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PRINCIPLES OF DISPLAY AND CONTROL DESIGN FOR STRIKE REMOTELY PILOTED VEHICLES (RPVs)

Lawrence J. Fogel, et al

Decision Science, Incorporated

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13. ABSTRACT

Principles of display and control design for Remotely Piloted Vehicles (RPVs) were investigated. The difficulties which arise from lack of kinesthetic feedback and problems associated with communicating adequate information to the remote pilot were considered. Attention was focused on the strike mission. A series of experiments were conducted to examine the pilot/subject's ability to control the RPV in flight and perform certain targeting maneuvers under different display and control situations.

The outside-in mode of attitude display was preferred in spite of the pilot's training and experience with the conventional inside-out display. A combination of these display modes was found to improve performance. The position mode control stick was found to be superior to the conventional rate control stick. The method of sensor mounting (stable platform vs. fixed-to-the-airframe) resulted in different levels of performance with the various heads-up attitude displays. Particular strategies were devised for the effective use of remote sensor directional control (slewing) and zoom. Additional techniques for improving RPV performance and certain opportunities for further investigation are identified.

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PRINCIPLES OF DISPLAY AND CONTROL DESIGN FOR STRIKE RPVs

FINAL REPORT

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INTRODUCTION

The research reported here was based on an unsolicited proposal which was accepted by the Human Resources Research Division, Advanced Research Projects Agency, Department of Defense and the Engineering Psychology Programs, Office of Naval Research, U. S. Navy. This proposal was an outgrowth of previous studies performed by Decision Science, Inc. in modeling the human operator in flight control, in devising logical methods which now form the basis of a computer program used in support of the Differential Maneuvering Simulator, Langley Research Center, NASA, and in the analysis of other aspects of military aircraft and weapon systems.

The potential military value of Remotely Piloted Vehicles (RPVs) is recognized. The design operation of such equipment systems poses certain new man-machine problems which must now be resolved. Extensive experience has already been gained in the flight control of target drones and certain missiles which are equipped for remote televisual guidance. But the prospect of sophisticated electronic defense measures and the requirement for precise maneuvering against heavily defended targets has generated a particular interest in improving the displays and control of the RPV console.

Obviously, much of what has been learned about the design of displays and controls for manned aircraft remains relevant. There is also a considerable background of knowledge derived from previous operations involving military RPVs (although these were not so named). Yet certain questions remain unanswered. These concern the subtle relationships which determine figure versus ground discrimination in remote control, disorientation, difficulty in handling a responsive vehicle without kinesthetic feedback, and difficulties due to incomplete telemetry and the potential effects of ECM. It is necessary to consider the degree to which data processing can be performed onboard the vehicle in that this affects the processing the human operator must perform in his control of the mission. Other questions concern the innate capability held by the pilot.

With these questions in mind, this investigation began with a review of alternative RPV missions and the general principles of display and control design for manned aircraft. Attention was then focused on the one-way strike mission. Later this was enlarged to include multiple targets and return of the RPV for recovery. In this study the control station remained stationary, thus unaffected by the g-forces which might disturb the human operator if he were situated in another aircraft or aboard a ship while in control of the RPV.

The investigation reported herein was conducted under Contract No. N00014-72-C-0196. It should serve as a step

toward improved display and control design for the above-referenced weapon systems and set the stage for further investigation of principles applicable to the design of displays and controls for other RPV missions, including reconnaissance, jamming, intelligence gathering, air superiority, and so forth.

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REPORT SUMMARY

This investigation was intended to definitize certain principles of display and control design suitable for RPVs engaged in the strike mission. Such vehicles may deliver conventional or laser guided weapons against heavily defended targets then return to friendly territory for recovery.

A review of the principles of display and control design suitable for manned aircraft flight control revealed the need for additional displayed information to overcome the pilot's lack of immediate kinesthetic and proprioceptive feedback and the potential limitation imposed by the communication channel between the console and the RPV.

An initial experiment explored the fundamental princples pertinent to the use of attitude prediction as well as modes of attitude display and flight control. Subjects of different levels of experience were evaluated in their performance of a simulated strike mission. This involved the flight of a conventional RPV in accordance with a scenario which included descent, the effects of atmospheric turbulence, video ECM, and a final maneuver to strike the target.

It was determined that performance was degraded through the use of a predictive attitude display which offered only information concerning pitch and roll. The outside-in mode of display was preferred by almost all subjects, including those holding significant piloting experience. It was equal in

performance to the conventional inside-out display. The position control stick (that is, wherein the attitude is in direct correspondence with the control stick displacement) was found superior to the conventional rate control stick.

Additional experiments based upon this preliminary knowledge were then conducted within a more realistic simulation of the mission, making use of a moving map and television camera video display generating technique. This simulation provided the pilot/subject with a heads-up view of what might be seen through a televisual sensor mounted in the RPV. Here subjects were restricted to designated Naval Aviators. The conventional attitude display indicator (ADI) served as the performance standard while alternative heads-up attitude displays were compared in terms of mission performance criteria.

As in the preliminary study the outside-in display mode was preferred, the moving aircraft symbol being easier to interpret especially when used with a rate control stick. Control reversals (error in direction of initial control movement to correct a suddenly imposed attitude disturbance) were taken to indicate a deficiency in the display design. The inside-out display mode produced fewer reversals in roll while the outside-in mode produced fewer reversals in pitch. This led to the conception of a combination display which presented roll attitude in an inside-out mode and pitch attitude in an outside-in mode.

This new display was compared to the conventional displays and was found to be superior in terms of the overall frequency of control reversals. It was also preferred by the subjects. Such a combination display mode proved to be particularly suitable for flight control when the sensor is fixed to the RPV airframe. The outside-in mode is more suited for use with the sensor mounted on a stable platform. Smoothing of the aircraft movement through the use of a low frequency-pass display mounting did not offer any significant benefit. Fixing the sensor to the airframe improved flight control, but mounting the sensor on a stabilized platform aided performance of the crucial target attack maneuver.

It is worthwhile to consider switching the display function from fixed mounting to stabilized platform mounting during the course of the mission or of using two pilots,* each operating the RPV in a different mode of performance, that is, by mission phase.

Reorienting the sensor (slewing) in two dimensions was found to be useful. However, a careful strategy in this regard was essential. Specifically, sensor control should not be concurrent with attitude control. Zoom control of the sensor can be of particular value provided a suitable strategy is followed: Zoom should not be used while slewing. Zooming-in can be used for target identification with zooming-out used during the approach to the target in order to improve aiming accuracy.

* One using a fixed sensor, the other using a stabilized sensor, both sensors being mounted on the same RPV.

Other problems pertinent to RPV flight control were examined through experimental procedures, pilot/subject interrogation, and a detailed review of their simulated flight performance. The findings of this study should contribute to the design of displays and controls which can be used to ensure effective strike mission performance by RPVs ranging in size from mini-RPVs through conventional aircraft. Implications for further research are indicated.

EXPERIMENT I

Problem Statement

After reviewing the generally accepted principles of display and control design for manned aircraft (as described in an appendix of the Second Semi-Annual Technical Report submitted under this contract), attention was first focused on the need for gaining greater understanding of remote attitude control. Should the RPVs attitude be presented in the conventional manner (an inside-out perspective, that is, by means of a moving horizon display) or should the RPV pilot be offered an outside-in presentation (with the aircraft symbol moving as it would appear if the pilot was always on a stable platform situated behind the aircraft)?*

A second question concerns the lag in pilot response when controlling an RPV, presumably due to his lack of kinesthetic sensation**. A third fundamental consideration is the type of control mode. Conventional aircraft are

*Some of the many studies of inside-out versus outside-in attitude displays for manned aircraft were referenced in prior reports under this contract. Although certain additional modes falling between these two extremes were noted, a new and different combination was conceived in this study.

**Safety chase pilots familiar with the landing of both manned and unmanned full-sized aircraft report that it is easy to distinguish between these two situations in view of the larger errors during final approach committed by unmanned aircraft. The pilot, being remote, cannot sense errors as quickly as he would if he were onboard. Here again, there has been considerable work demonstrating the value of anticipatory displays but not as these pertain specifically to RPVs.

controlled through a rate stick; that is, the first derivative of aircraft angular movement is determined by the stick angular displacement.* The position stick mode of control is simpler. Here the attitude of the aircraft is in direct correspondence with the angular displacement of the control stick. Rate stick control is all-attitude while the position stick normally limits the range of attitudes the aircraft can assume. This restriction is acceptable for the purpose of a strike mission.

In the initial phase of the investigation there was also concern for the amount of knowledge and experience required to properly control RPVs. This consideration grew out of a recognition of the high cost of training pilots and their scarcity for RPV assignment, especially in times of combat. It would certainly be advantageous if personnel of lesser qualifications could equally well perform RPV flight control. The first experiment therefore involved five classes of pilot/subjects, ranging from naive through qualified Navy Attack Pilots.

Experimental Procedure:

Equipment was assembled and configured in order to simulate the dynamics of a typical RPV (such as the BQM-34E). The simulation program was written to represent a typical jet-driven subsonic drone in six degrees of freedom. This program was prepared for the EAI 8400 Digital Computer. The EAI 8800 Analog Computer was used to perform the required

*it is recognized that rotational damping causes some saturation effect for large displacements.

coupling to the displays and controls. The equations of motion were solved in real-time using a forty millisecond frame rate. The output at each frame was three rotational and three transitional rate terms of vehicle motion. These rates were integrated in real-time to provide the current attitude and positional information required for driving the display devices.

Both horizontal and vertical wind velocity components were generated through a digital simulation. These magnitudes were assumed constant over the entire airframe with the wind restricted to occurrence below 1,000-foot altitude. In essence, the simulation provided a normal level of turbulence with some degree of gusting and a constant directional bias. Specifically, the turbulence was of 30 feet per second mean and 5 feet per second standard deviation, with 1 foot per second standard deviation in the vertical plane, and with a 30 feet per second constant bias at -45°, this with a standard deviation of 2°.

The digital simulation program sampled the digitized analog inputs from the RPV flight control console each frame in terms of control stick position, thrust, roll, pitch, and rudder trims. These were then used to up-date the flight control values for the next real-time solution of the equations of motion. Control mode data input prior to each run specified whether the attitude control stick would control position or rate. Discrete signal functions were also provided

to the simulation regarding a secondary task (suppression of an audio tone), expansion of the altimeter scale by a factor of ten, and target detection. Certain parameters of flight performance were recorded on the EAI 8875 8-channel strip chart recorder. Figure 1 indicates the information flow through the system.

The RPV response was presented to the pilot/subject by means of an attitude display generated on a cathode ray tube. This could be made to operate in either inside-out or outside-in mode. The intended course, airspeed, and altitude were shown on a plotting board with the actual ground track plotted in real time as the experiment proceeded.

Additional pointer-on-scale instruments provided airspeed, altitude, heading, and range with respect to the target. Indicator lights above the altitude and range displays designated their operational status. The target itself only appeared on the CRT when the aircraft was within suitable range. It first appeared as a dot on the horizon, then grew with the approach to more clearly define a 250 feet diameter circle inscribed around the ground target. The subject was instructed that this target was 50 feet high. The constant effects of enemy video ECM took the form of "snow" superimposed on the CRT display "video signal."

Various controls were offered on the console, including push buttons to allow the subject to change the altitude scale and indicate his having detected the target. A small two-axis

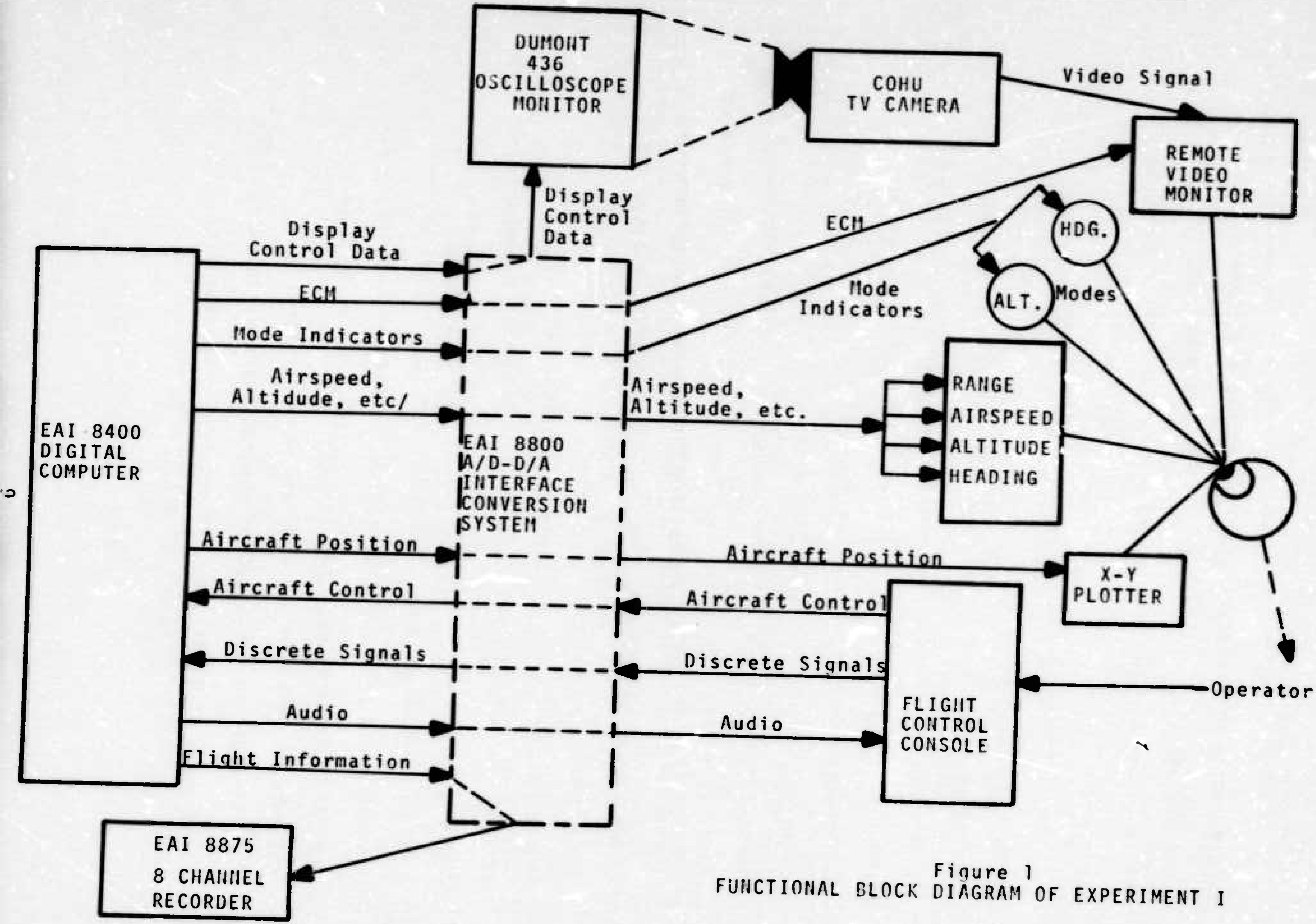


Figure 1
FUNCTIONAL BLOCK DIAGRAM OF EXPERIMENT I

control stick with appropriate trim controls allowed him to guide the vehicle. This control stick could be made to operate in either the position or rate modes. Figure 2 shows the experimental set-up.

Two different scenarios of comparable difficulty were used, the RPV being initially acquired over friendly territory at an altitude of 2000 feet some thirteen to fifteen miles from the target. The subject was then required to reduce its altitude. In so doing he encountered increasing atmospheric turbulence. His task was to follow the intended course over enemy territory (in spite of the jamming), to approach the target at an altitude between 300 and 500 feet, and to dive into the center of the target. The subject was also presented with a secondary task which required him to depress a pedal whenever a tone was heard. This action switched off the randomly actuated audio signal. The total on-time of this signal was taken as in inverse measure of the pilot's ability to perform additional tasks beyond that required for the mission. Various measures of performance were taken including cross-track error, altitude error, airspeed error, time required for target detection, probability of target acquisition computed as a function of time, handling quality of the vehicle, angle of impact, and miss distance.

Five distinct classes of subjects were called upon. The first group of eight included only naive subjects, that is,

Experiment I - Set-Up
Figure 2

individuals holding automobile driving experience but no knowledge or experience in aircraft flight control. The second group of eight included engineer non-pilots...individuals familiar with flight control principles but having no personal experience in this art. The third group of eight included model aircraft pilots who had achieved significant status in this regard. The fourth group were volunteer Navy fighter pilots from Miramar Naval Air Station. The last group of eight were volunteer Navy attack pilots from Lemoore Naval Air Station.

Each subject filled out a questionnaire concerning his background and experience, was given the Witkin Embedded Figures Test and received an identical briefing before participating in the experiment. Those unfamiliar with flight control were shown a film of low altitude flight to give them a perspective on the real task. After completing the simulated mission they were debriefed and asked to write a commentary on the experiment and their subjective response.

The experimental design was a 3 x 2 x 2 x 2 factorial model. The independent variables were subject groups (Navy Attack Pilots, Model Aircraft Pilots, and Engineer Non-Pilots);* control stick (rate vs. positional); attitude display (inside-out vs. outside-in); and attitude prediction (real-time or prediction). Preliminary measurement reveal that a prediction time interval of 3.7 seconds for pitch and 0.7 seconds

*the other two groups were scored but not used in this analysis.

for roll served to minimize mid-course attitude control errors under the imposed level of turbulence. Linear extrapolation of these times into the future generated the predictive attitude mode of display. Details of the experimental design and methodology can be found in Appendix A.

Results:

Statistical analysis of the measures taken revealed no significant difference in performance under the two different modes of attitude display. Surprisingly, all Navy pilots preferred the outside-in mode of attitude display.

Although the predictive attitude display was expected to benefit performance this was not the case. In general, the subjects found greater difficulty when using this mode. Under prediction, the attitude was apparently more affected by the turbulence and thus more difficult to control. Note that this predictive display was neither compensatory nor pursuit in that information concerning the present attitude of the aircraft was not provided to the subject in any manner. The adequacy of the performance without predictive attitude display justified eliminating further exploration in this regard. Some subjects indicated that predictive heading and range displays might be of value.

The position control stick was found to be superior to the rate control stick for all subjects in terms of average cross-track error and target miss distance. Although the

rate stick was conventional, all subjects preferred the position stick. In fact, they demonstrated better performance with the position control stick in terms of the crucial target approach maneuver. Obviously, the Navy pilots benefited least from the position stick, because of their greater flight experience. Evidently, the simpler relationship between this control and the aircraft attitude is of benefit. Most significantly, the position control stick gave the subject sensory attitude feedback thus obviating the need for visual contact with the attitude display. This was particularly beneficial under ECM conditions.

In general, Navy pilots proved superior in terms of their ability to fly safely at low altitudes and in terms of target miss-distance. No significant difference was noted between groups in terms of cross-track error. No significant performance difference was found with respect to enroute flight control measures between the subject groups, but significant differences did exist in terms of the crucial maneuver (which was found difficult for all subjects regardless of group). Quality of performance of the groups in this regard was found to be in the order expected; that is, as a function of kind and amount of experience.

Analysis of scores revealed that the Witkins Embedded Figures Test offered greatest significance as a predictor of subject performance. Second to this measure was the experience of the subject in controlling model aircraft.

Other factors contributed far less to any ability to identify subjects who are likely to perform well in such a simulation. Considerable learning was observed in subjects having little military flight experience. The learning curves show that an order of magnitude improvement can be achieved in the first two hours of simulator experience.

Conclusion:

The preliminary conclusion on the basis of this experiment concerned the mode of control stick operation. The position stick was found to be superior in terms of performance of the strike mission. The use of a predictive attitude display without reference to present attitude was not found to be useful and, in fact, often degraded performance. No significant determination could be made with respect to the inside-out versus outside-in heads-up attitude display. Further refinement within a more realistic simulation was called for in this regard. Detailed examination of the findings formed the basis for devising further experiments which were planned in terms of weapon, mission simulation, and prospective data analysis.

Summary of independent variables:

Attitude display: inside-out vs. outside-in
Attitude prediction: present attitude vs. future attitude
Control mode: rate stick vs. position stick
Subject groups: naive vs. engineers vs. Naval pilots

INTRODUCTION TO FURTHER EXPERIMENTS

The findings of the first experiment emphasized the need for more realistic simulation. A moving map drive mechanism was devised and placed before a television camera mounted to view the map from a moving platform with variable orientation with respect to the map (as shown in Figure 3), all this being driven in accordance with the response of the flight of the aircraft during the simulated mission. A new computer program was written to represent the dynamics of the FDL-23 aircraft. This program was suitably coupled to the above-referenced mechanism.

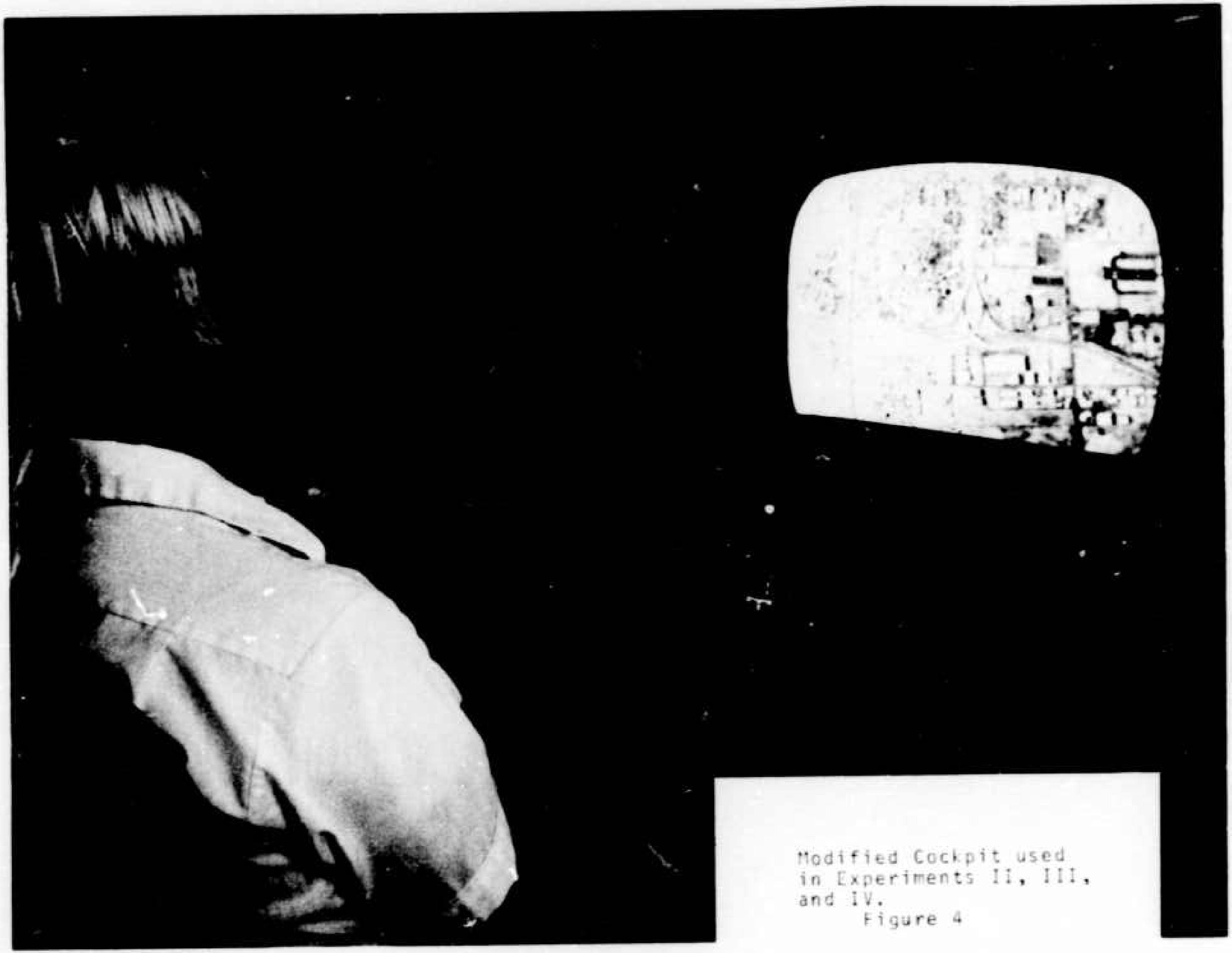
A cockpit was configured with console including conventional flight instruments as might be required in support of the proposed mission. A 21-inch CRT offered the heads-up video display and appropriate symbology. Specifically, the conventional instruments included a two-axis attitude direction indicator (ADI), a horizontal situation indicator (HSI), an airspeed indicator, an altimeter, a rate-of-climb indicator, a sideslip angle indicator, a g-meter, control surface position indicator, and a clock. Means were also provided for covering certain of these instruments as required by the experimental procedure. See Appendices B and C for further details.

The controls offered to the pilot/subject included a center stick for flight control, rudder pedals, pitch and roll trim controls, and a side-stick camera control mounted for left-handed actuation which directs the sensor in pitch

Moving Map and Camera Set-Up for Experiments II, III and IV.
Figure 3

and yaw. A trim switch on top of the camera control was provided for zoom. Push buttons and a trigger on the center stick were used for indication of target recognition and for weapon release. Figure 4 shows a portion of this cockpit with the sensor looking directly down at a point on the ground.

The first of these more realistic simulation experiments was intended to investigate the potential conflict between the attitude displays and sensor mounting modes. Indeed, this experiment generated further questions in this regard and thus led to Experiment III. The result of Experiments II and III were used in the design of Experiment IV which investigated display and control problems associated with the crucial phase of the strike mission. All subjects in the following experiments were volunteer Navy fighter pilots from Miramar Naval Air Station. In each case they were briefed as to the intent of the experiment, completed questionnaires similar to those used for the first experiment, were debriefed and asked to write a commentary on their experience in the simulation.



Modified Cockpit used in Experiments II, III, and IV.
Figure 4

EXPERIMENT II

Problem Statement

The literature review and findings of Experiment I led to new questions concerning display modes. Specifically, does the sensor mounting affect the pilot's ability to control the RPV? Is there truly a difference between the pilot's performance with inside-out and outside-in heads-up attitude display? Is there a difference between the performance using these heads-up display modes and the conventional ADI? Finally, does the mode of sensor mounting affect performance under various modes of heads-up attitude display?

Experimental Design:

General Procedure

The scenario for this experiment required the pilot/subject to acquire the RPV, fly it to a specific altitude (either 5,000, 5,500, 6,500 or 7,000 feet), and bring the vehicle to straight and level flight using the displays available in that portion of the procedure. At an appropriate time (unknown to the pilot) the attitude of the aircraft was disturbed by a hard over surface command of variable duration. The subject had been previously instructed to maintain level flight especially if severe disturbances were encountered. His ability to hold altitude during this level flight attitude control portion of the simulated mission was not measured.

The RPV was acquired at an altitude of 6,000 feet at 450 knots airspeed. The pilot was not evaluated on his ability to maintain any particular speed. Throttle control was not used during these runs. After attaining level flight at the desired altitude the hard over surface command was introduced. Recovery from this deviation automatically terminated the run. These runs varied in duration from ten to sixty seconds.

The test conductor initiated each run from a remote, hand held console and was in continuous visual and verbal contact with the subject. Before each run the subject was instructed as to the display and control configuration he would experience. The test conductor introduced the problem after noting that the situation was appropriate. He exercised the option of terminating the run before its normal completion if flight control was lost or recovery could not be regained within an acceptable time span. The display and control configuration and computer operation required for simulation could be controlled from the test conductor's console. Upon completion of the data transcription resulting from each run, the test conductor would alter the display configuration in accordance with the experimental procedure and prepare the subject for the next run.

Each subject was instructed to perform a secondary foot-tapping task, thus indicating his level of stress and residual

channel capacity. Difficulties encountered in interpreting this secondary task caused it to be abandoned after the first series of experiments.

The experimental procedure was devised to control the display and control configuration available in each run over a variety of flight conditions as might be encountered in the strike mission. The available information to the pilot/ subject and his control authority was successively restricted while his task remained to maintain flight control through induced attitude anomaly. To repeat, the purpose of this experiment was to measure the subject's ability to cope with ambiguous and incompatible display formats in his execution of simple RPV flight control.

The first intent was to identify problems which might arise in a situation wherein the RPV pilot views conflicting display formats (that is, wherein outside-in and inside-out displays are used concurrently). The second objective was to order the display combinations in terms of their support for the basic requirement of attitude control of the RPV.

Seven different measures of performance were taken on this task, the subjects being scored on four continuous variables: aircraft movement as a function of pitch and roll, time required for recovery to level flight, response time of the subject, time to the first correct movement of

the control, and three discrete measures pertinent to control reversals: the number of reversals in roll, in pitch, and the total number. See Appendix D for details of performance measurement. See Appendix E for details on the subjects and Appendix F for details on the experimental design, methodology and data reduction.

This experiment was conducted in three separate phases. These phases involved the same basic performance scores, tasks, scenarios, and equipment. The difference in the phases was the independent variables under study. The various phases, the independent variables for each phase, and the reasons for the different phases were as follows:

Phase One

In Phase One the independent variables consisted of three levels of sensor mounting mode (fixed to airframe, smoothed to eliminate jitter, stabilized to eliminate all aircraft attitude movement); and four levels of attitude presentation mode (ADI only, video aircraft symbol only, both ADI and this aircraft symbol, no attitude display). The fixed conditions were the sensor downlook angle (15°) and the length of time the aircraft was exposed to the attitude perturbation (20-computer cycles, or approximately one second). Two subjects were utilized in this phase.

Phase Two

Two considerations were involved in the evolution of Phase Two. The most important was the discovery that the

aircraft symbol attitude display used in Phase One was inadvertently responding as an inside-out display instead of as an outside-in display. This was a plug-board error but the resulting data was not discarded and was analyzed because of its potential value in studying inside-out versus outside-in behavior. The second consideration in development of Phase Two was the sensor downlook angle of 15°. It was apparent that this downlook angle with the 30° wide by 24° high sensor field of view did not allow the pilot much useful attitude feedback from the video (that is, the horizon line was not visible under level flight and pitch down conditions). This was particularly noticeable when the pilot had no other available attitude information (that is, no ADI and no video aircraft symbol). This led to a lack of controllability of the RPV and failure to complete the prescribed task.

To correct for this situation Phase Two differed from Phase One in that the aircraft symbol now responded as intended and the sensor downlook angle was reduced to 7.5°. In Phase Two the perturbation length was also controlled as an independent variable. Two levels of perturbation time were used. One level was 1 sec as used in Phase One and the other level was of shorter time (approximately 180 milliseconds). The shorter time was introduced because the subjects were responding before the perturbation was completed.

Phase Three

Phase Three was developed as a result of the subjects behavior in Phases One and Two. Specifically, they demonstrated persistent use of the ADI when it was available. This resulted in disregarding the video as a reference. This behavior might have been in response to a conflict between the outside-in video and the inside-out ADI display. Note that the pilots are very familiar with the ADI, both from their training and experience.

In Phases One and Two it was discovered that pilots could not, or at least found it very difficult to, perform the task when they had no attitude displays, that is, fly with only the video, altimeter, and rate of climb indicator. It was expected that there would be difficulty with this configuration especially with a stabilized sensor, but not to the degree observed. It was generally found that the subjects could complete the task with the fixed sensor mounting mode, although the performance was significantly degraded. Control was virtually impossible with the smoothed and stabilized sensor mounting modes under these conditions. Further testing with no attitude display was therefore dropped.

It then appeared appropriate to refine the study by looking at inside-out versus outside-in with attitude displays and sensor mounting modes. Phase Three consisted of the

following independent variables:

1) sensor mounting mode (fixed or stabilized), and
2) attitude display mode (video aircraft symbol or video artificial horizon line).

The four possible combinations of these two variables gave the four possibilities of an inside-out or outside-in sensor mounting mode (fixed or stabilized) versus an inside-out or outside-in attitude display (artificial horizon or aircraft symbol).

The subjects were instructed to use the ADI, which was always uncovered, but were cautioned that it may malfunction (which was deliberately the case when the perturbation was introduced). Because the ADI was "unreliable" the subjects depended upon the heads-up configuration*for attitude information. The perturbation time was held constant (180 milliseconds) and the task completion tolerances were relaxed so that the subject was required to maintain the vector sum of pitch and roll within three degrees of zero for three seconds. (Analysis revealed the prior requirement of two degrees for three seconds tolerance was excessively stringent.)

RESULTS

Phase One:

Response times were generally shorter when background video motion cues were available, that is, with fixed sensor

*For the purpose of this study the term "heads-up" is taken to refer to displays on what would be the windscreen if the pilot were onboard the vehicle.

mounting mode. Completion times were longer and the amount of aircraft movement was noted to be greater when the video aircraft symbol responded as an inside-out display compared to the video artificial horizon and ADI. Use of an aircraft symbol video attitude display increased the number of control reversals.

<u>Phase Two</u>:

The time expended prior to initiating correct movement in response to the perturbation was shorter with the ADI as compared to the video aircraft symbol. Recovery times were longer and the aircraft movement greater with use of the video aircraft symbol. These conditions were true for both perturbation duration times. Less aircraft movement was observed when the video information more nearly resembled the normal inside-out motion-cue condition. In this phase the video aircraft symbol was observed to contribute to the number of overall control reversals and, in particular, to the roll reversals.

<u>Phase Three</u>:

It was noted that the time to respond to the perturbation decreased when the video attitude display and sensor mounting were in the same modes. The artificial horizon was responsible for better performance in terms of time to initiate correct movement, however, this display contributed to increased pitch reversals. It was again observed

that the video aircraft symbol display contributed to the number of roll reversals. Greater experience with the video aircraft symbol did not improve the subjects performance in terms of reversals. Perhaps some minimum percentage of control reversals is an intrinsic character of human performance. More detailed discussion of these results can be found in Appendix G.

CONCLUSIONS

Observations across the three experimental phases revealed that the ADI contributed to superior performance when compared with the other two attitude displays. The ADI and video artificial horizon displays both contributed to shorter times to initiate correct control movement. And yet these displays were responsible for more control reversals in pitch attitude as compared to the aircraft symbol.

It was observed that overall performance with respect to response times was generally improved with normal motion cues (fixed sensor mode) as the video background information. A tendency was also observed toward improved efficiency in terms of less aircraft movement in this mode. Response times also decreased when video attitude display/sensor mounting modes were compatible.

In general, the video aircraft symbol was a less desirable display. It contributed to significantly longer recovery completion times, greater aircraft movement, a

larger number of control reversals and, particularly, more reversals in roll. Completion times and aircraft movement measures were also adversely affected when the video aircraft symbol responded as an artificial horizon. These factors may be attributable to both the direction of the video symbol movement and some intrinsic characteristic of the symbol format. As stated earlier, experience in using the video outside-in aircraft symbol did not reduce the number of control reversals.

It was observed that a large, sudden perturbation of short duration affecting aircraft attitude contributed to a more serious control problem, that is, longer recovery times and greater aircraft movement. Therefore, such a perturbation was required to produce subject responses resulting in more sensitive measures of display suitability.

Analysis of the Embedded Figures Test scores with performance scores on control tasks revealed definite tendencies toward significant positive correlations. (See Appendix L) Thus, even with a relatively homogenous group, such as these pilot/subjects, differentiation in performance measures were predictable from the use of a relatively simple test.

Summary of Independent Variables

Phase One

Attitude display mode (3 levels)

- Inside-out aircraft symbol video attitude display
- ADI attitude display
- Inside-out aircraft symbol video and ADI attitude display

Sensor mounting mode (3 levels)

Fixed

Smoothed

Stabilized

Phase Two - Independent Variables

Attitude display mode (3 levels)

Outside-in aircraft symbol video attitude display

ADI attitude display

Outside-in aircraft symbol video and ADI attitude display

Sensor mounting mode (3 levels).

Fixed

Smoothed

Stabilized

Perturbation time (2 levels)

One second duration

180 milliseconds duration

Phase Three - Independent Variables

Attitude display mode (2 levels)

Inside-out attitude display (artifical horizon)

Outside-in video attitude display (aircraft symbol)

Sensor mounting mode (2 levels)

Fixed (inside-out)

Stabilized (outside-in)

EXPERIMENT III

Problem Statement

The third experiment was conducted to explore a combination heads-up attitude display and investigate pilot performance under more stringent conditions, this on the basis of Experiment II, Phase 3. In that study, two video attitude displays (aircraft symbol and artificial horizon) and two sensor mounting modes (fixed and stabilized) were contrasted under simulated flight conditions. The particular outcome of interest was that the aircraft symbol (an outside-in display) reduced the number of pitch reversals and the artificial horizon (an inside-out display) reduced the number of roll reversals.

Hazards identified with low altitude RPV missions include disorientation as a result of navigation difficulties and premature termination as a result of control error. Rapid decision-making is mandatory. Effective flight control under these conditions requires positive control handling and quick aerodynamic response, particularly as compared to higher altitude flight as previously studied. Could a display be conceived which would maximize the beneficial features of each of the two contrasting attitude displays? Although the display-producing equipment available for this study was somewhat limited in terms of graphics, a composite display was generated.

This display consisted of an aircraft symbol depicting only pitch and an artificial horizon symbol only used for roll. Figure 5 depicts this display along with the other attitude displays. The aircraft symbol simply moved up or down showing pitch ascent or descent respectively (outside-in mode). The artificial horizon responded to only roll, displaying this in an inside-out format. The aircraft symbol was also made more realistic (with longer wings and shorter tail) than the previously used symbol. This change was accomplished to allow greater opportunity for the subjects to recognize aircraft motion by making the smaller symbol movements more obvious and appropriate.

The problem was to compare this new display with the previous displays in order to discover a further principle of display and control.

Experimental Design

Experiment III was concerned with comparing the combination video attitude display with the other attitude displays under conditions of low-altitude flight. Two independent variables were considered. The first was the video attitude display, consisting of three levels: aircraft symbol, artificial horizon, and the combination. The second variable was the sensor mounting mode consisting of two levels: fixed and stabilized. Further details on experimental design, subjects, performance measurement, and data reduction may be found in Appendices D, E, and H.

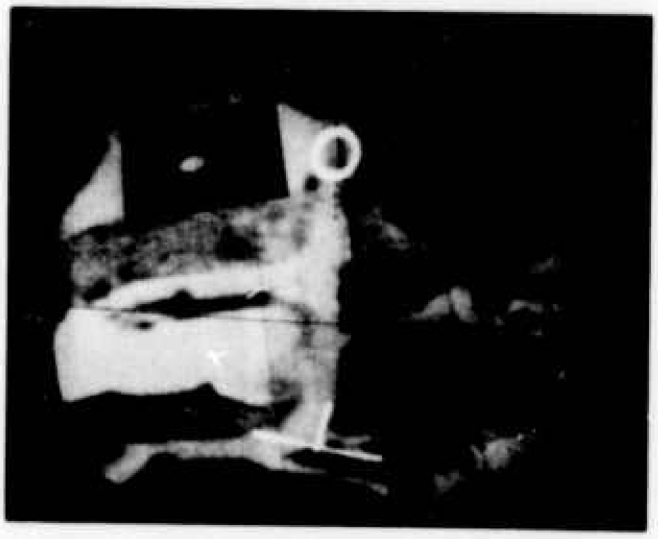


Figure 5A
Video Aircraft Symbol Attitude Display

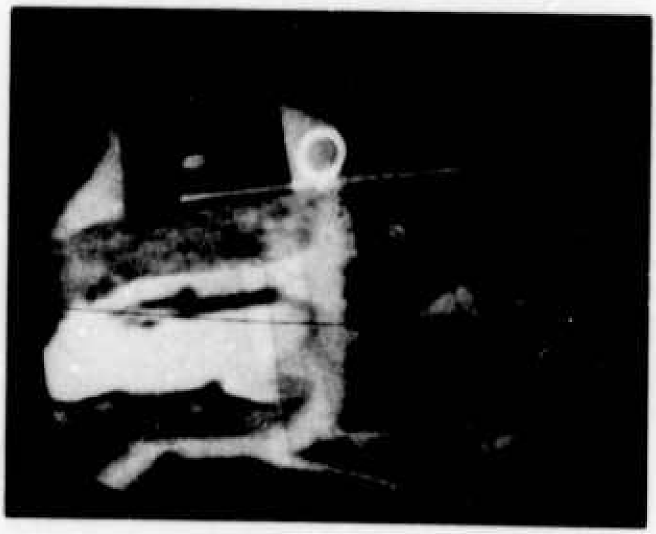


Figure 5B
Video Artificial Horizon Attitude Display

Figure 5C
Video Combination Attitude Display

These attitude displays for experiment Three are depicting a pitch down right bank attitude. The sensor is slewed looking down at the target. The reticle is used for weapon aiming.

Figure 5

Results

The results of Experiment III revealed that the combination video attitude display decreased the number of control reversals as compared to the other two attitude displays. A significant increase in the number of roll reversals was noted with use of the aircraft symbol. This symbol contributed to significantly shorter response time.

The artificial horizon was significantly less efficient for aircraft flight control (that is, there was more aircraft movement). In this experiment, the subjects demonstrated significant learning with respect to aircraft flight control. Details of results are found in Appendix I.

Conclusion

It was shown that the combination display promises improvement in terms of minimization of control reversals when compared to other displays. For fixed sensor mounting, the aircraft symbol showed significantly improved performance. Learning to control an RPV under difficult conditions was amply demonstrated within this experiment. If the stabilized sensor mounting mode is required (for example, as in target detection), the aircraft symbol should be used to display attitude. In all other cases the combination display should be used.

Summary of independent variables:

Attitude display: artificial horizon (inside-out) vs. combination display vs. aircraft symbol (outside-in)

Camera mounting: fixed to airframe (inside-out) vs. stabilized (outside-in).

EXPERIMENT IV

Problem Statement

The purpose of this experiment was two-fold. First, to ascertain the ability of experienced Navy pilots in "flying" a realistic RPV strike mission. Second, to identify realistic display and control options for the RPV strike missions and to compare these, once determined.

Several different controls and displays are available for a potential strike RPV. These can replace the familiar (to experienced pilots) in-flight feedback and enhance performance. There is the potential of sensor slewing to replace the in-flight requirement for head turning for target search, navigation, orientation, and so forth. There is the possibility of sensor zooming to replace the lack of "depth perception" to enhance target search and attack performance. There are alternate possibilities of sensor mounting. One is to have the sensor fixed to the RPV airframe, thus giving picture feedback similar to that experienced from inside the aircraft. Another alternative is to stabilize the sensor with respect to aircraft pitch and roll. This would provide picture feedback more similar to the RPV pilot's actual situation, that is, from outside the aircraft. Previous experiments have determined compatible heads-up attitude displays for these two sensor mountings. (See Experiment II, Phase 3 and Experiment III for these results.)

Experimental Procedure

The scenario designed for this experiment was intended to simulate target acquisition and attack. The subject took control of the aircraft at an altitude of 1,000 feet, an air-speed of 325 knots, heading of North, at approximately six miles due south of the target. These initial factors were chosen to simulate the RPV having been vectored into the target area. The subject was instructed to "fly" the RPV to an altitude of 500 feet and to maintain that altitude until he was 2-1/2 miles from the target (approximately 25 seconds from start of flight). This simulated a low-altitude penetration of enemy territory. At that point he was near sighting range of the target and climbed to an altitude of 1,500 feet and began target search. This action simulates the beginning of a "pop-up" maneuver. Upon sighting the target the subject was to depress a switch indicating target recognition. The subject then prepared for a target attack by placing the reticle on the target while diving onto the target. At an altitude of 700 to 500 feet and with the target in the reticle the subject activated weapon release. After weapon release the subject was to regain altitude. At this time the scenario ended presuming the RPV to be returned to base by the same

method it was brought to the target area. The completed mission took from 60 to 100 seconds, depending on the subject's control of the RPV.

Each subject performed this task four times for each target/display-control configuration. There were six target selections, one for each of the six display-control configurations presented to the subject. The required mission simulated a multi-RPV attack with sequential target strikes being performed by the same pilot.

This experiment investigated the relative worth of various display and control options for a strike mission. The display options were fixed sensor mounting with combination video attitude display (see Experiment III) and stabilized sensor mounting with an aircraft symbol video attitude display. The control options were presence or absence of fixed rate zoom control and presence or absence of positional sensor slewing control. Two types of targeting tasks were also investigated. One task used a simulated "dumb" weapon (one that follows the aircraft trajectory upon release). The second task used a simulated "smart" weapon (one that homed on a target designated by the sensor orientation at release). After release the "smart" weapon is assumed to impact on the ground where the sensor was pointing at the time of release. Note that without slewing these tasks are essentially identical, so that three different slewing/weapon configurations were used instead of four.

Performance for Experiment IV was measured over the three stages of the scenario. Stage one performance (low altitude flight) was measured by calculating the altitude, airspeed, and heading averages and standard deviation and thus comparing these to the desired values. Stage two (target search) performance was measured by the target recognition time, and the slant range to the target at this time. The third stage (target attack) performance was measured by the weapon release time, weapon release slant range, weapon release altitude, and down-range and cross-range of the impact.

Eight pilots/subjects from Miramar Naval Air Station were utilized in this experiment. Four of these subjects used the combination attitude display of fixed camera mode and four used the aircraft symbol/stabilized mode. Each subject performed four repetitions on each of six different display-control configurations (two zoom options and three weapon/slewing options). The configurations were presented in a 2 x 3 balanced order for each of the two attitude display/sensor mode options. Further details of subjects, performance measurement, experimental design, methodology, and data reduction are described in Appendices D, E, and J.

Results

No single independent variable resulted in significant differences on the performance variables. Further analysis of the error mean square (EMS) values for each set of four repetitions uncovered several interesting interactions. The availability of zoom control increased the target recognition slant range EMS (i.e., resulted in less consistent slant range for weapon release). There was significant interaction between the attitude display/camera mode and the task variables. This interaction was with respect to the enroute variable of altitude, the weapon release time, and miss distance. In all these cases the interaction indicated two orderings of the task options depending on the attitude display/sensor mode being used. With the combination/fixed mode the ordering (from low to high EMS) was no slew/'dumb' weapon, slew/'dumb' weapon, and slew/'smart' weapon. With the aircraft symbol/stabilized mode this order was reversed. There were indications of similar interaction with the zoom and task variables. With zoom, the ordering (again low to high EMS) was no slew/'dumb' weapon, slew/'dumb' weapon, slew/'smart' weapon. With no zoom control available this ordering tended to be reversed. Details of results for this experiment are found in Appendix K.

Conclusions

A cautious interpretation of the results from this experiment was required. No single mode or control proved to be significantly better overall. The results did show that certain control and display combinations were conditionally better than others. Specifically, the best combination was the stabilized sensor mode with aircraft symbol attitude display, slewing with a "smart" weapon, and no zoom control. If the stabilized platform or the "smart" weapon is not available then the sensor should be fixed with the combination attitude display, no slewing with a "dumb" weapon, and zoom control available.

Summary of independent variables:

- attitude display/camera mode: Aircraft symbol/stabilized vs. combination/fixed to airframe
- zoom: no zoom vs. zoom capability
- slew/weapon type: no slew/"dumb" weapon vs. slew/"dumb" weapon vs. slew/"smart" weapon.

MINI-RPV SIMULATION EXPERIMENT

The simulation of aircraft dynamics was modified so that these reflect the dynamics of a typical mini-RPV. One of the pilots who served in the preceding experiment was requested to control this vehicle through the performance of two simulated missions. In the first his task was a strike mission similar to that described for experiment IV. He was then requested to perform a laser designation mission wherein the task was to maintain the reticle on the target for as long as possible.

A cursory examination of the resulting data revealed that the mini-RPV can be controlled in a similar manner to the full scale aircraft. This pilot/subject could perform the tasks as well or even better with the mini-RPV. He demonstrated an ability to maintain attitude control under severe gusting conditions even with a rate stick although this mode of attitude control reflected poorer performance. The mission assignments were successfully accomplished.

OVERALL CONCLUSIONS

After preliminary consideration of alternative RPV employment, attention was focused on the strike mission with intended recovery. Experimental evidence was then gathered on the different modes of attitude display and control for such an RPV. The positional control stick was found to be superior to the rate control stick. Mounting the sensor fixed to the airframe was superior to other sensor mounting modes, that is, stabilized mounting with respect to pitch and roll or smoothed mounting. Smoothing in the sensor mounting provided no advantage in any regard. Results of this initial experiment identified several attitude display/control options suitable for more realistic experiments. Additional options were found worthy of investigation.

A combination attitude display (inside-out for roll presentation and outside-in for pitch) was found to be superior to either single mode of presentation if the sensor is fixed to the airframe. Note that this is not what would have been expected according to the conventional dictum of human engineering.

Various conclusions can be drawn from these experiments. If a fixed-to-the-airframe sensor is used, the artificially induced sensor movement (termed "slewing") degrades performance. Slewing is not desirable with a "dumb" weapon (one which follows the vehicle trajectory from the point of launch).

Slewing aids performance if a stabilized platform is available for sensor mounting, especially with a "smart" weapon (one which impacts at the aiming point). If a free choice is possible among these options then the stable platform "smart" weapon system with slewing control is optimal. A positional control stick is best for all phases of this mission.

IMPLICATIONS

Remotely piloted vehicles for strike missions can certainly be automated far beyond the levels considered in this study. They may be pre-programmed to navigate to fixed enemy targets, and return for recovery without guidance from the control station. Certainly such autonomous behavior reduces the danger of detection, exposure to ECM, and enemy defensive weapons.

Such automation can only be achieved at considerable expense...but cost has been a key concern ever since the initial RPV concept. If such weapons are to be available in adequate numbers, they must be of low cost and with less automation, thus there is greater dependence on the remote human operator. In addition to performing enroute guidance and flight control in addressing the target, he can select alternative targets of opportunity. He can evade enemy weapons or other threats and monitor the developing situation with respect to weather, the performance of the vehicle, the adequacy of any required support functions, and so forth. The above-described experiments served to clarify certain ambiguities relating to the suitability of manual control modes as these might be called upon for performing the RPV strike mission. These results provide a foundation for designing less costly RPV systems and for performing the necessary trade-off to

determine the most suitable level of avionic sophistication. By direction, this study did not concern target detection per se, in that this has been studied elsewhere.[1, 2, 3, 4]

Preliminary attention was focused upon RPV attitude control. The classic conflict between inside-out and outside-in modes of attitude display was addressed using subjects ranging in experience from naive through fully qualified Navy attack pilots. In spite of significant pilot training and experience, a natural pre-disposition appeared in favor of the outside-in mode (even though the pilots could perform equally well using either mode). Replacing present attitude by the expected attitude did not benefit performance. The higher frequency components resulting from such linear rate prediction imposed great difficulty on the non-pilots. Although the experienced pilots could cope with what appears as greater turbulence, they continue to fly "ahead of the vehicle" and therefore compound the errors of prediction.

[1]W. E. Leninger, The Electro-Optical System as as Aid to Aerial Detection and Identification of Ground Targets: (US Naval Missile Center: Editorial Division, 1966).

[2]R. A. Bruns et al, Dynamic Target Identification on Television as a Function of Display Size, Viewing Distance, and Target Motion Rate: (Naval Missile Center: Editorial Branch, 1970).

[3]Frank D. Fowler and Dr. Daniel B. Jones, Target Aquisition Studies: (Martin Marietta Corporation, 1972).

[4]Daniel B. Jones, A Collection of Unclassified Technical Papers on Target Acquisition: (Office of Naval Research: Martin Marietta Aerospace, 1972).

Apparently, real time attitude presentation is satisfactory for RPV control. Pursuit and compensatory predictive attitude displays might also be of some value, however, detailed exploration of this did not appear to be justified.

The positional mode of control stick was found to be superior to the conventional rate control mode. Although the position stick is limited in attitude, it provides a simpler display/control relationship and facilitates precise flight control. Pilots evidenced no particular difficulty in using this mode of control. Question remains as to whether some nonlinear positional mode stick might be superior to the simple linear attitude versus control stick displacement function used in this experiment. Experiments in this regard are to be conducted at the Human Engineering Laboratory, Naval Weapons Center, Point Mugu. The possibility of combining position and rate modes was considered, although no experiments were performed in this regard.

Comparison of the inside-out and outside-in modes of attitude displays revealed that outside-in was better for pitch control but that inside-out was better for roll control. It is generally believed undesirable to mix modes of display and yet the experimental results indicate the benefit to be realized by a combination attitude display wherein the aircraft symbol moves only in pitch while the horizon symbol moves only in roll. In point of fact, this combination

attitude display enables superior performance when the sensor is fixed to the airframe. Apparently, the aircraft symbol moving in the vertical dimension compensates for the lack of kinesthetic feedback which is most pronounced in pitch-changing maneuvers.

Use of a restricted field of view, due to the sensor, introduces the need for scaling the horizon symbol movement so as to properly reflect pitch change over a significant range. But this transformation introduces a disparity between the motion of the artificial horizon and the background in the vicinity of the horizon. The actual horizon* moves farther and faster than the artificial horizon, although both move in the same direction. This difference in speed can result in an apparent opposite movement of the two horizons. This difficulty is not present with the moving aircraft symbol since its motion is in the opposite direction. Here again, the outside-in mode of display appears to be most suitable.

Question remains as to the suitability of this display for RPV operators situated onboard another aircraft or ship in that under such circumstance, the controller is subject to uncorrelated g-forces. When a stabilized sensor mounting is used, the outside-in mode of display should again be superior.

* "Actual horizon" refering to the horizon as seen from onboard the RPV through the sensor.

Sensor slewing can be of great value but its use depends upon the nature of the weapon and the sensor mounting. In general, the more complex the pilot's task (that is, the less the level of automation) the less desirable slewing becomes. In the limit, a fixed-to-the airframe sensor forces the pilot to identify the target within a moving background while a stabilized platform allows him to observe a steady field. Here, slewing is more desirable. If provided with a "dumb" weapon, the pilot must align the vehicle with the target before weapon release, but with a "smart" weapon he can simply fly close to the target and aim the weapon through sensor slewing. Obviously, such slewing is therefore mandatory for a "smart" weapon. With a "dumb" weapon, slewing only helps if there is the availability of a stabilized platform.

The experimental findings only concern a position sensor control stick for slewing in two dimensions (pitch and yaw). There seems to be no need for rate slewing sensor control. Disorientation was experienced when pilots attempted to slew and change RPV attitude simultaneously. Evidently the subjects cannot maintain separate orientation regarding the vehicle and the sensor. To overcome this problem the pilots were instructed not to take simultaneous redirection of the sensor and the aircraft. This strategy removed the difficulty. Serious consideration may also be given to use of a helmet-mounted display as a less restrictive means for

obviating this problem.[5] Head movement is intrinsically sensed by the human operator so that simultaneous slewing and aircraft flight control might be performed without loss of orientation. Such a "heads up" display might also provide an omnidirectional view from the RPV, provided additional sensors are suitably mounted and switched as a function of the controller head movement.

Penetration of enemy territory may call for low altitude flight, thus a pop-up maneuver may be required for effective targeting. Here manual slewing control is appropriate although automatic slewing could be used if there has been previous lock-on to the target.

The use of the sensor zoom capability requires an appropriate strategy. The wide field of view is used in search for the target. Magnification is increased for target identification and a fixed rate de-zoom should be used during approach to the target. This maintains fixed sensitivity of aiming as the range decreases. In essence, the target remains at the same visual angle until the point of weapon release. In this mode, a reticle can be used to indicate range to the target and thus the appropriate time for weapon release. Alternatively, the size of the aircraft symbol can be used to indicate range.

[5] Jeffrey D. Grossman, Flight Evaluation of Pilot Sighting Accuracy Using a Helmet-Mounted Sight: Technical Note 4011-17: (Naval Weapons Center: Weapons Development Department, 1973).

SUGGESTIONS FOR FURTHER RESEARCH

Although only televisual sensing was simulated in this study, it seems reasonable to extend the findings to cover FLIR and other imaging sensors. The use of alternative filters, multi-spectral sensing or multiple sensors may enhance target detection, flight control and mission performance.[6, 7, 8] Reference is made to the recent literature on this matter.

Only conventional shape displays were used in this investigation. It is possible, however, that the nature of the sensor might call for different shape of display for best presentation. Once again, the nature of the mission, sensor capability, and the human operator must be mated in the design of the interface.

The presentation of color should aid the human operator, particularly with respect to targeting. Pseudo-color (that is, the introduction of color as a function of sensed grey scale level) may prove worthwhile. Pseudo-black-and-white might be of use in field situations which cannot accomodate

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[6] Ronald A. Erickson, Human Factors Research Techniques With Television. Naval Weapons Center, China Lake, Ca., NWC TP 5072, January 1971.

[7] R.A. Bruns, A.C. Bittner, Jr., and R.C. Stevenson, Effects of Target Size, Target Contrast, Viewing Distance, and Scan Line Orientation on Dynamic Televisual Target Detection and Identification. (AIRTASK A340 5313/225-B/2F00524001), August 17 1972.

[8] Herschel C. Self and Steve A. Heckart, TV Target Acquisition at Various Frame Rates. AMRL-TR-73-111, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, September 1973.

the complexity of color generation. This subject deserves a separate investigation.

Stereoscopy might also be useful for improved targeting. However, sensors mounted on the wingtips provide only a short baseline and thus restrict depth display. Alternatively, time separated frames can be presented to each eye. This requires careful scaling and, since the baseline is along the flight path, its primary value is with respect to side-looking targets. Another possibility is use of the forward air controller's sensor, thus providing a very large baseline. Here there should be great stereoscopic depth, but sophisticated data processing would be required to maintain proper scaling. Holographic displays may find application here.[9]

Additional instrumentation should provide the operator with data pertinent to mission performance. There might well be vertical tape displays of the kind found in modern aircraft, energy management displays using predictive indices, displays which flag unusual circumstance or emergency conditions, auditory displays which replace the pilot's visual monitoring of conditions by audition and olfaction. Particular attention should be given to the display of ECM or weapon illumination and to the use of burst communication for additional security. Significant portions of the mission could be in an autonomous mode. Various studies have examined video presentation and modified frame rates.

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[9] T.J. Harris, R.S. Schools, G.T. Sincerbox, D.W. Hanna, D.G. Delay, "Holographic Head-Up Display -- Phase II Final Report" JANAIR Report 680709, March 27, 1970.

Further studies are required to determine multiple RPV operational procedures. Enroute control may well be separated from conduct of the crucial maneuver in view of difference in function and the desirability of providing a single operator with repetitive control of the direct attack. The displays and controls for these operators should be considerably different (as indicated above). In what way should RPV operations be integrated with those of manned aircraft in the performance of strike missions? To what extent do the above findings relating to the strike mission carry over to reconnaisance missions and other requirements? Are there ways to select and train RPV pilots so as to relieve the requirement on those pilots already trained to fly manned aircraft? These and other questions may be addressed as an extension of this investigation.

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APPENDIX A

Design and Methodology for Experiment I

Data were taken to permit a factorial design. The various effects considered included the three groups of pilots (Navy Attack Pilots, Model Aircraft Pilots, and Engineer Non-Pilots), the attitude display (outside-in versus inside-out), the attitude control stick mode (position versus rate), and the use of predicted attitude (prediction versus no prediction). The experiment was planned to allow each subject to fly each display control combination at least once over each scenario, that is, 16 runs per subject. A 3 x 2 x 2 x 2 balanced factorial design was established. The desired data were incomplete on some subjects due to machine malfunctions and other problems. To compensate, the data were analyzed by the General Linear Model Method which provided the capability for using unequal numbers of observations in each cell.

The General Linear Model had sufficient sample size to allow for estimation and testing of interaction and the significance of differences between the design variables with respect to dependent variables of flight control (cross-track error) and targeting (in terms of miss distance). The model also allowed for statistical control of learning in the use of run order as a covariate, thus the order of display presentation was randomized for each subject.

There were two dependent variables; the cross-track error averaged across both scenarios for each display control situation for each subject yielding eight obervations,

and the miss distances at the end of each run, thus providing a total of 16 observations for each subject (two for each display control situation). Note that miss distances greater than 10,000 feet were discarded as the subject was considered not to have seen the target any time during the mission.

A program was written to monitor the performance in terms of flight control capability and ability to perform the crucial maneuver. Input data concerned the particular scenario, the eight different display/control situations, four continuous and seven discrete variables as a function of real time. These variables included airspeed in knots, altitude in feet, cross-track error in nautical miles, probability of success (hitting the target), north-south miss-distance in feet, east-west miss-distance in feet, time of target detection, total on-time of sound in the secondary task in seconds, total flight time in seconds, and impact angle (recorded only when there was a hit).

Discrete variables were part of the printout. The cross-track error and probability of success were manually integrated through use of a planimeter. Airspeed and altitude were reduced by establishing three critical points along the scenario wherein nominal airspeed and altitude errors occurred. In addition, the instructed airspeed and altitude profiles were referenced in order to obtain integers representing the total number of excessive deviations from

the instructed profile, that is, errors beyond ± 150 feet in altitude, ± 20 knots in airspeed. The total number of instances wherein these limits were exceeded were counted by mission phase in order to provide a measure across subjects.

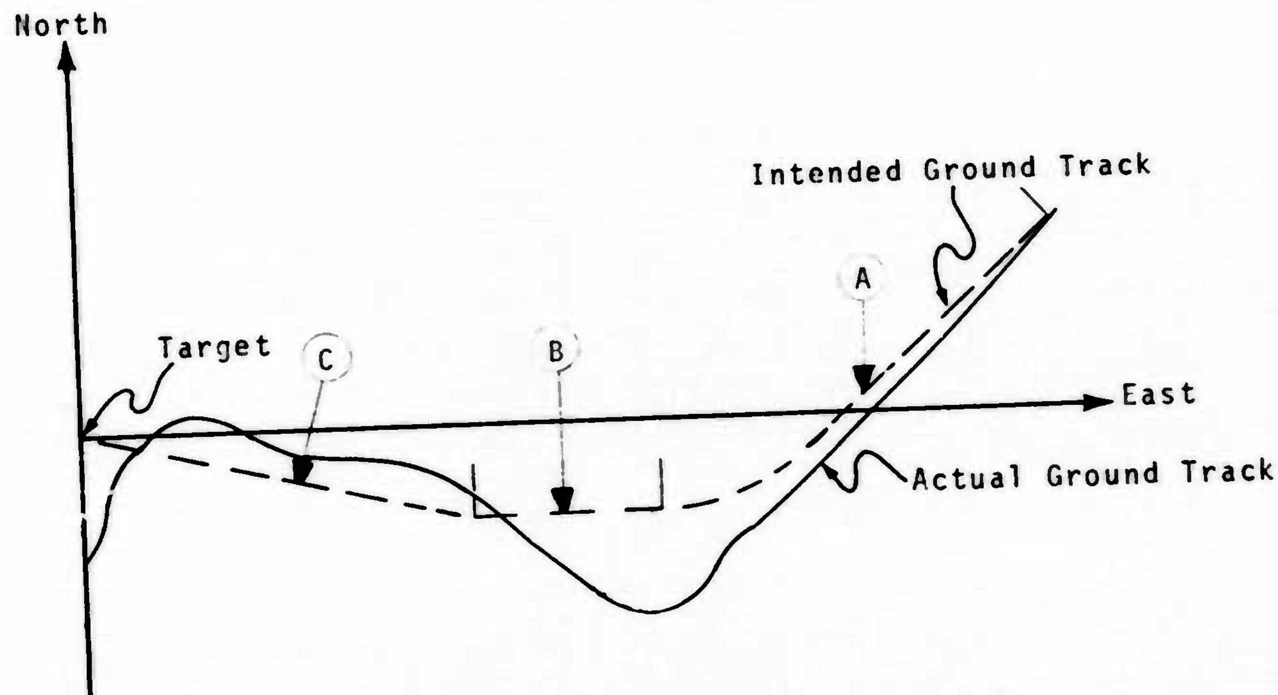
Specifically, the intent here was to identify only significant errors in flight control. If the subject maintained the initial thrust setting of 90 percent, his altitude descent would almost certainly fall within this tolerance up to about one mile from the target. At that point, a deliberate effort is required by the pilot to descend to the proper altitude in order to impact the target. Thus, naive subjects who choose not to control this variable until the very end were not penalized. However, pilots could well take advantage of the additional flexibility afforded through thrust control and better execute the mission well within the tolerance, both with respect to altitude and airspeed.

The particular tolerances chosen were determined through preliminary measurements on both pilots and naive subjects thus taking into account the effect of turbulence at low altitude. A symmetrical error weighting was chosen in view of the danger of clobber on the low side and of missing the target through overflight on the high side. The airspeed tolerance was also symmetrical about the instructed airspeed in view of the danger of stall and of having too short a time to perform the crucial maneuver. Within these parameters, subjects who made long but controlled individual

excursions outside the tolerance were penalized as much as those who made single short excessive deviations in either direction. In this experiment the object was not to score the ability to perform accurate flight control but rather to remain within the acceptable band of performance.

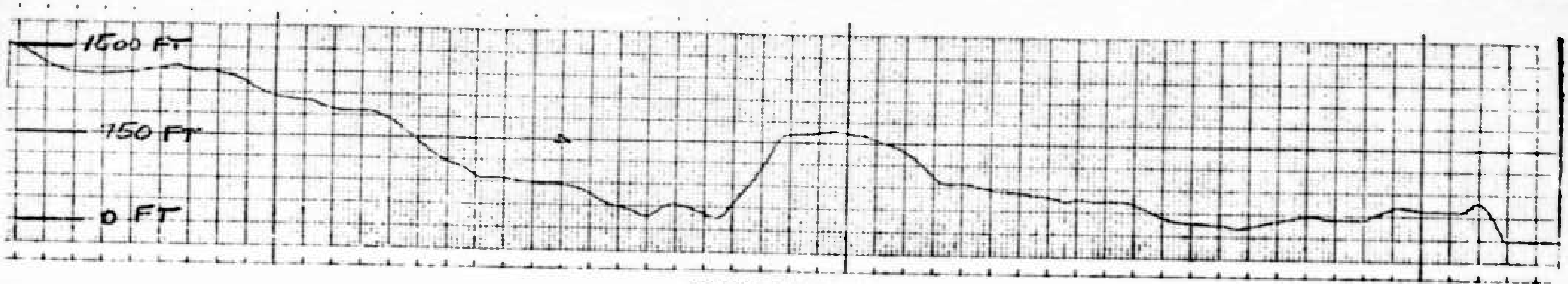
The computer simulation program represented the dynamics of the vehicle in its flight over the terrain and provided some degree of automated data reduction. A portion of the recorded data appeared on paper tape, a portion on the ground track plotter and a portion on the console typewriter. To illustrate, the computer generated pilot performance as indicated in Figure 6 , which shows the plot and the ground track course of a subject flying with an inside-out presentation, without prediction, and with rate stick control. This particular trace was generated by a Model Aircraft Pilot/ Subject on mission profile No. 2. The solid curve represents the ground track while the dashed curve represents the intended course in three phases. In Phase A, the subject attempted to maintain 95% thrust and descend to 1,000 feet. In Phase B, he intended to maintain the thrust and descend to 800 feet. In Phase C, he was instructed to reduce his speed to about 300 knots and enter the target domain at an altitude of 200 feet.

Figure 7 illustrates the performance of a subject in terms of his altitude profile, probability of success, and corresponding terminal performance as indicated by the computer program. Specifically, the probability of success

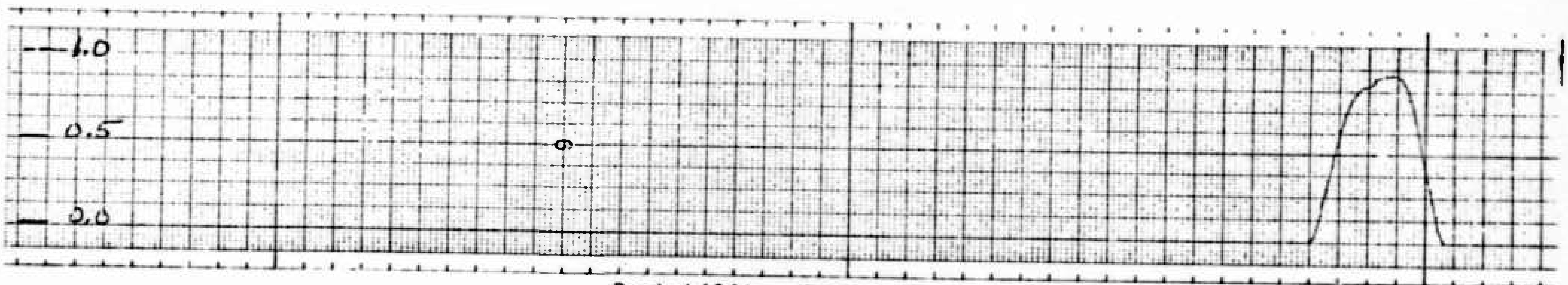


Sample x-y Plotter Mission Profile

Figure 6



Altitude-Feet



Probability of Success

```
OOPS
 RPV OPR     MODEL AIRPLANE N6     DATE    9-17-72  MAP NO.005C      SCENARIO NO8
     NORTH              -19800
     EAST                -1586
     ALTITUDE               -1
 TARGET RECOGNITION TIME          1.60

 TOTAL TIME              263.
```

Terminal Console Output

Figure 7
Sample Output of Type I-B Model A/C Pilot Performance

program calculated a variable ranging from zero to one at every time frame during the simulated flight, this probability being calculated as the product of three expectations: the probability of target detection, the probability of collision with the ground, and the probability of loss of the RPV due to ground fire (these latter two probabilities being empirical functions of altitude only). In essence, these probabilities took the form of exponential functions, the former descending from 1.0 at zero altitude to zero at 400 feet, the latter beginning at 600 feet and rising to about 0.4 at 1600 feet.

The General Linear Model provided a methodology for estimating the effects of several independent variables and their interaction with a dependent variable. An equation was derived expressing the dependent variable as the sum of various independent variable effects, interaction effects or covariate effects (See Tables 1A, 1B and 1C). The independent variables were discrete classificatory variables and the analysis required observation of at least one value of the dependent variable for each particular combination of independent variables (with more than one being needed for estimation of interaction). The covariate for the exercise had to be an ordinal variable. An observed covariate value was needed for each corresponding observation of the dependent variable.

In this particular case, the dependent variable (being cross-track error or miss-distance) was presumed to be affected by the independent variables of groups of pilots, mode of attitude display, time scaling of attitude display, mode of control stick operation, and the covariate run order (that is, the sequence of the particular display combination).

In this case, the general linear model precluded the possibility that the variation of dependent variables could be accounted for by differences in the groups, differences between the predicted and non-predicted attitude, difference between the position and rate stick modes, interactions between the independent variables and the effect of the covariate run order (which is a reflection of learning).

TABLE 1A

General Linear Model Equation

$$X_{mijk\ell} = M + G_i + V_j + S_k + P_\ell + GV_{ij} + GS_{ik} + GP_{i\ell} + VS_{jk} + VP_{j\ell} + SP_{k\ell} + GVS_{ijk} + GVP_{ij\ell} + GSP_{ik\ell} + VSP_{jk\ell} + GVSP_{ijk\ell} + B^*R_{mijk\ell} + e_{mijk\ell}$$

where

$m = \left\{\begin{matrix} 1,2,3,\ldots,8 \text{ for cross-track error} \\ 1,2,\ldots,16 \text{ for miss-distance} \end{matrix}\right\}$ = repetition number

$i = 1,2,3$ = group

$j = 1,2$ = attitude display presentation mode number

$k = 1,2$ = control stick mode number

$\ell = 1,2$ = attitude prediction mode numbers

$X_{mijk\ell}$ = dependent variable (cross-track error or miss distance)

M = overall mean

G_i = group effect

G_1 = Navy Attack Pilot/Subject effect

G_2 = Model Aircraft Pilot/Subject effect

G_3 = Engineer Subject effect

V_j = altitude display effect

V_1 = Inside-out mode effect

V_2 = Outside-in mode effect

S_k = control stick effect

S_1 = Rate stick mode effect

S_2 = Positional stick mode effect

P_i = prediction effect

P_1 = Prediction mode effect

P_2 = No prediction mode effect

GV_{ij}, GS_{ik}, $GP_{i\ell}$, VS_{jk}, $VP_{j\ell}$, $SP_{k\ell}$ = second order interaction effects

GVS_{ijk}, $GVP_{ij\ell}$, $GSP_{i\ell k}$, $VSP_{jk\ell}$ = third order interaction effects

$GVSP_{ijk\ell}$ = fourth order interaction effect

b = coefficient of the covariate

$R_{mijk\ell}$ = covariate, run order = order in which the mth subject from group i "flew" display combination $jk\ell$

$R_{mijk\ell}$ = 1,2,...,8

$e_{mijk\ell}$ = random error inherent in performance, assume zero mean for $e_{mijk\ell}$ and homogeneous variance.

TABLE 1B

Mathematical Constraints on General Linear Model

$$0 = \sum_{i=1}^{3} G_i = \sum_{j=1}^{2} V_j = \sum_{k=1}^{2} S_k = \sum_{\ell=1}^{2} P_\ell = \sum_{i=1}^{3} GV_{ij} = \sum_{j=1}^{2} GV_{ij} = \sum_{i} GS_{ik} = \sum_{k} GS_{ik} = 0$$

$$0 = \sum_{i} GP_{i\ell} = \sum_{\ell} GP_{i\ell} = \sum_{j} VS_{jk} = \sum_{k} VS_{jk} = \sum_{j} VP_{j\ell} = \sum_{\ell} VP_{j\ell} = \sum_{k} SP_{k\ell} = \sum_{\ell} SP_{k\ell} = 0$$

$$0 = \sum_{i} GVS_{ijk} = \sum_{k} GVS_{ijk} = \sum_{\ell} GVS_{ijk} = \sum_{j} GVP_{ij\ell} = \sum_{k} GVP_{ij\ell} = \sum_{\ell} GVP_{ij\ell} = 0$$

$$0 = \sum_{i} GVSP_{ijk\ell} = \sum_{j} GVSP_{ijk\ell} = \sum_{k} GVSP_{ijk\ell} = \sum_{\ell} GVSP_{ijk\ell} = 0$$

TABLE 1C

Final General Linear Model Equation After Solution of Constraint Equation* and Substitution

$$X_{mijk\ell} = M + y_{1,n_1}G_1 + y_{2,n_2}G_2 + y_{3,n_3}V_1 + y_{4,n_4}S_1 + y_{5,n_5}P_1 + y_{6,n_6}GV_{11} +$$

$$y_{7,n_7}GV_{21} + y_{8,n_8}GS_{11} + y_{9,n_9}GS_{21} + y_{10,n_{10}}GP_{11} + y_{11,n_{11}}GP_{21} +$$

$$y_{12,n_{12}}VS_{11} + y_{13,n_{13}}VP_{11} + y_{14,n_{14}}SP_{11} + y_{15,n_{15}}GVS_{111} +$$

$$y_{16,n_{16}}GVS_{211} + y_{17,n_{17}}GVP_{111} + y_{18,n_{18}}GVP_{211} + y_{19,n_{19}}GSP_{111} +$$

$$y_{20,n_{20}}GSP_{211} + y_{21,n_{21}}VSP_{111} + y_{22,n_{22}}GVSP_{1111} + y_{23,n_{23}}GVSP_{2111} +$$

$$b \times R_{mijk\ell} + e_{mijk\ell}$$

Where y_{r,n_r} = design variable = $\begin{Bmatrix} -1 & \text{depending on the constraint} \\ 0 & \\ 1 & \text{equation solution} \end{Bmatrix}$

The value of n_r is dependent upon i,j,k and ℓ.

*For example solving $\sum_{i=1}^{3} G_i = 0$ gives $G_3 = -G_1 - G_2$;

Solving $\sum_{j=1}^{2} V_j = \sum_{k=1}^{2} S_k = \sum_{\ell=1}^{P} P_\ell = 0$ gives $V_2 = -V_1$, $S_2 = -S_1$, and $P_2 = -P_1$.

More complex dependencies were derived for the interaction effects.

APPENDIX B
Equipment Description

Equipment used in Experiments II, III, and IV

Control Console:

The pilot/subject's console was modified from a two-place side-by-side cockpit. The controls consisted of a conventional center stick for pitch and roll control. Pitch and roll trim functions were provided by a trim switch on the control grip. Conventional rudder pedals were used for yaw control with trim being provided by a switch on the left console. The left console also included a throttle and sensor slew control stick. The sensor slew control stick provided two-axis slew control. The control had a detent center position and was otherwise unconstrained so that it would remain where positioned. A zoom switch was mounted on the sensor control handle.

The instrument panel is illustrated in Figure 8 . Directly in front of the pilot was located a conventional two-axis attitude direction indicator (ADI). Directly below the ADI was a horizontal situation indicator (HSI). To the left of these instruments were an airspeed indicator, an altimeter, rate of climb indicator, sideslip angle indicator, g-meter, and aviation clock. To the right of the

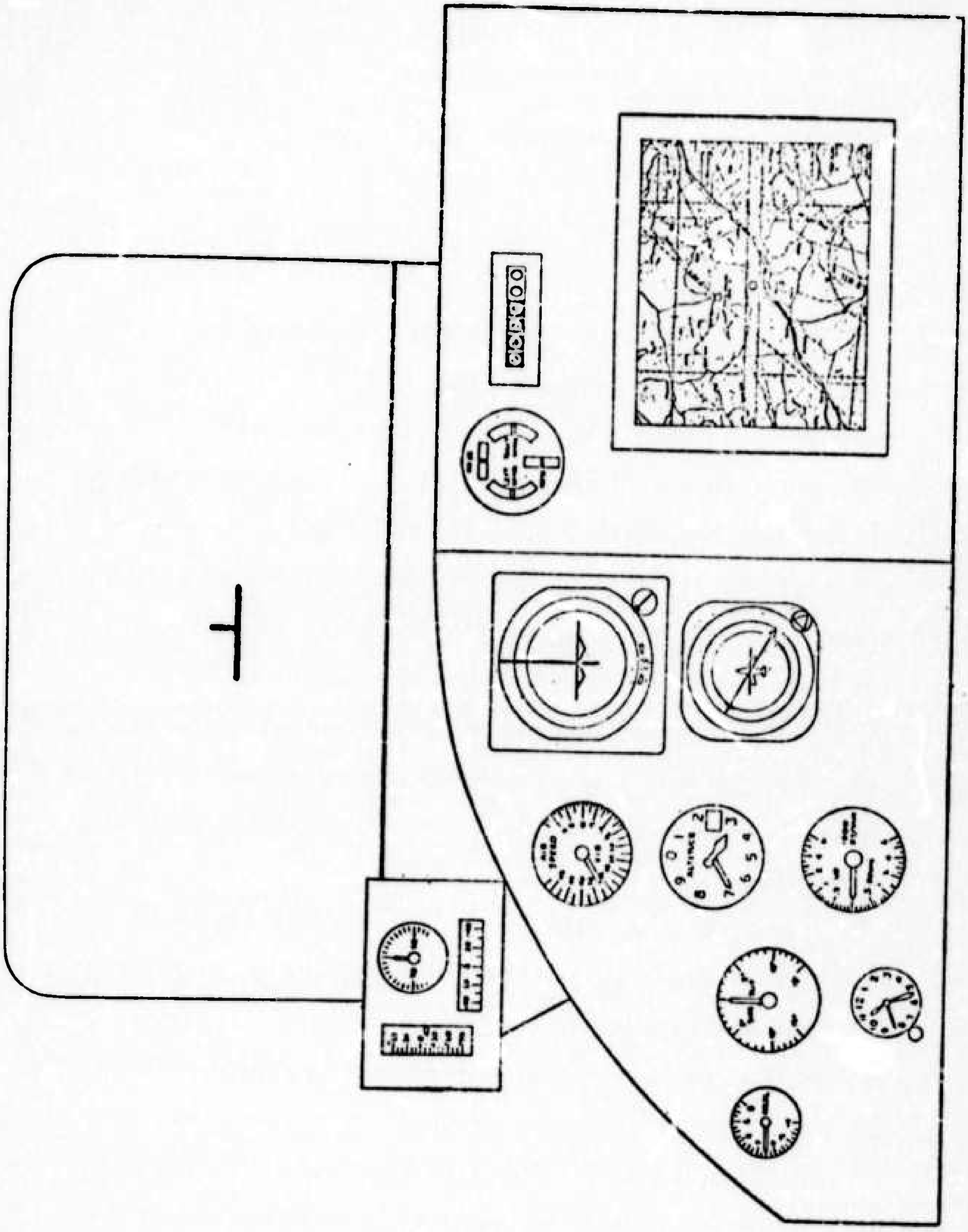


Figure 8 RPV Display and Control Instrument Panel

ADI-HSI instruments was a control surface position indicator and a timer.

Test Conductor's Control Panel:

The test conductor's control panel was hand-held and cable-mounted so that the test conductor could adopt the most convenient location for monitoring the experiment. The box contained three push buttons for controlling the simulation mode, ten switches for program options, and a four-position switch for selecting map options.

Visual Display Monitor:

Directly in front of the subject was a 21-inch video monitor driven by the visual display generator. The sensor image was presented on this monitor along with other symbology such as cross-hairs and a moving or fixed aircraft symbol. At the lower left corner of the monitor were located three indicators showing the sensor orientation angles relative to the vehicle.

Visual Display Generator:

The visual display generator consisted of a TV camera, optical bed, carriage system, and roller map assembly. Two large transparencies of the terrain were mounted on the map assembly. One of these was approximately nine feet wide by 30 feet long at a scale of 1500:1. This map represented the terminal terrain area to be used for low altitude flight. A continuous strip six feet wide and thirty feet long at

a scale of 15000:1 was used for higher altitude enroute flight phases. The computer system generated the motion command and automatically synchronized motion and positions between the maps. The visual display generated aircraft camera motion by travel along two carriages, movement of the map assembly, rotation of a Pechan Prism, and vertical and horizontal motion of the wide angle lens. The motion of the map assembly produced north-south motion. The outer carriage produced east-west motion, and the inner carriage produced altitude changes. The camera bed was inclined to look down at the map with a 15 degree angle from the horizontal. The field of view of the wide-angle lens was $\pm$ 80 degrees while the camera field of view was $\pm$ 15 degrees. By translating within the wide-angle lens field of view, the camera field of view could be yawed or pitched. A Pechan Prism was then used to roll the image and complete the three-axis rotation set.

Camera:

The video camera viewed a portion of the image produced by the optical system. This portion represented a field of view 30 degrees wide by 24 degrees high. The camera was a high resolution... 900 line camera. The camera control electronics also included hardware which allowed the superposition of other images on the video picture. This feature was used to simulate the moving aircraft symbol, artificial horizon combination displays, and gunsight reticle.

Video Monitor Displays:

Several graphic heads-up displays were generated on the video monitor. This was done by using the aircraft attitude outputs from the analog computer to drive various symbols on an oscilloscope. This oscilloscope was viewed by a separate video camera. The signals from this camera were mixed with the signals from the camera viewing the moving map terrain.

Three attitude displays were generated, an aircraft symbol, an artificial horizon, and a combination display. See Appendix H for further discussion of the combination display. A gunsight reticle was also generated in this manner. Further discussion of the gunsight is found in Appendix J.

Display-Control Configuration:

Figure 8 provides a layout of displays used in this experiment. A CRT display was located at eye level directly above the instrument panel. The essential instruments for this experiment were: the two-axis ADI, airspeed, altimeter, vertical speed indicator, control surface indicator, clock, and video displays. Other instruments available to the subject were accelerometer, Horizontal Situation Indicator, sideslip meter, and sensor angles. Controls available for the subject were: throttle, potentiometer for sensor alignment, trim switch, and an aircraft control stick (in proportional or rate mode).

Equipment Configuration:

The major components may be listed as follows:

COMCOR CI-5000 Analog Computer-implements vehicle simulation

Analog to Digital Converters	)	input-output
Digital to Analog Converters	)	processors for displays and control

Xerox Data Systems SDS 930 Digital Computer

Controlled video camera pointing angles.

Controlled communication between test conductor and vehicle simulation.

Calculated discrete values for data reduction.

Operator's (pilot) console (RPV controls and displays)

Test Conductor Control Panel

Video Monitor

Visual Display Generator

Moving Map Assembly

Camera and Carriage System

Video Symbol Generator

COCKPIT INSTRUMENTATION

Attitude Director Indicator (ADI)

- Roll Angle
- Pitch Angle
- Turn Rate
- Raw Glideslope

Horizontal Situation Indicator (HSI)

- Course (Set by the Navigation System)
- Heading Command
- Heading, True
- Heading Error (Difference between Heading and Course)

Altimeter

Airspeed Indicator

Rate of Climb Indicator (Vertical Speed Indicator)

Normal Accelerometer

Sideslip Angle Indicator - (Beta)

Mission Time Digital Clock - Elapsed time in seconds from the start of the mission.

Control Surface Indicator

- Rudder Angle
- Elevator Angle
- Aileron Angle

Angle of Attack - (Alpha)

Relative Sensor Position - Display of aircraft attitude relative to the TV camera attitude

- Camera Pitch Angle
- Camera Yaw Angle
- Camera Roll Angle

Video monitor heads-up displays

- Aircraft Symbol
- Artificial Horizon
- Combination Display
- Gunsight Reticle

CONTROL INPUTS

Flight Controls

- Center Stick - elevator and ailerons
- Rudder Pedals
- Pitch Trim, Roll Trim, and Yaw Trim

Camera Controls

- Control Stick - pitch and yaw
- Zoom Control

Auxiliary Controls (located on Flight Control Stick)

- Weapon Release
- Target Recognition

Test Conductor-Observer Controls

- Mission Parameter Entry Keyboard and Printer Console
- Mission Initiate, Terminate, and Abort
- Camera and Symbology Modes
- Disturbance Initiation

APPENDIX C
Mission Simulation
for Experiments II, III, and IV

Flight Simulation

The RPV Mission Simulator consists of four major blocks: the aircraft simulation, the control and evaluation program, the operator and test conductor stations, and the visual display generator. The relationship of these components is illustrated in Figure 9.

The RPV simulation is a six-degree-of-freedom simulation implemented on a COMCOR CI-5000 Analog Computer. The aerodynamic, mass property, and thrust data for this simulation was extracted from the report AFFDL-FGC-TM-72-18 "The Simulation Specification for the FDL-23 Remotely Piloted Vehicle". Linear aerodynamics, in general, were used to simulate the vehicle (the exception was the implementation of a quadratic drag polar). The data and equations are expressed in body axes.

The three force and three moment equations are implemented as follows:

$$\frac{F_z}{M} = \left(\frac{\rho S C_{Z_o}}{2M}\right) U^2 + \left(\frac{\rho S C_{Z_\alpha}}{2M}\right) UW \tag{1}$$

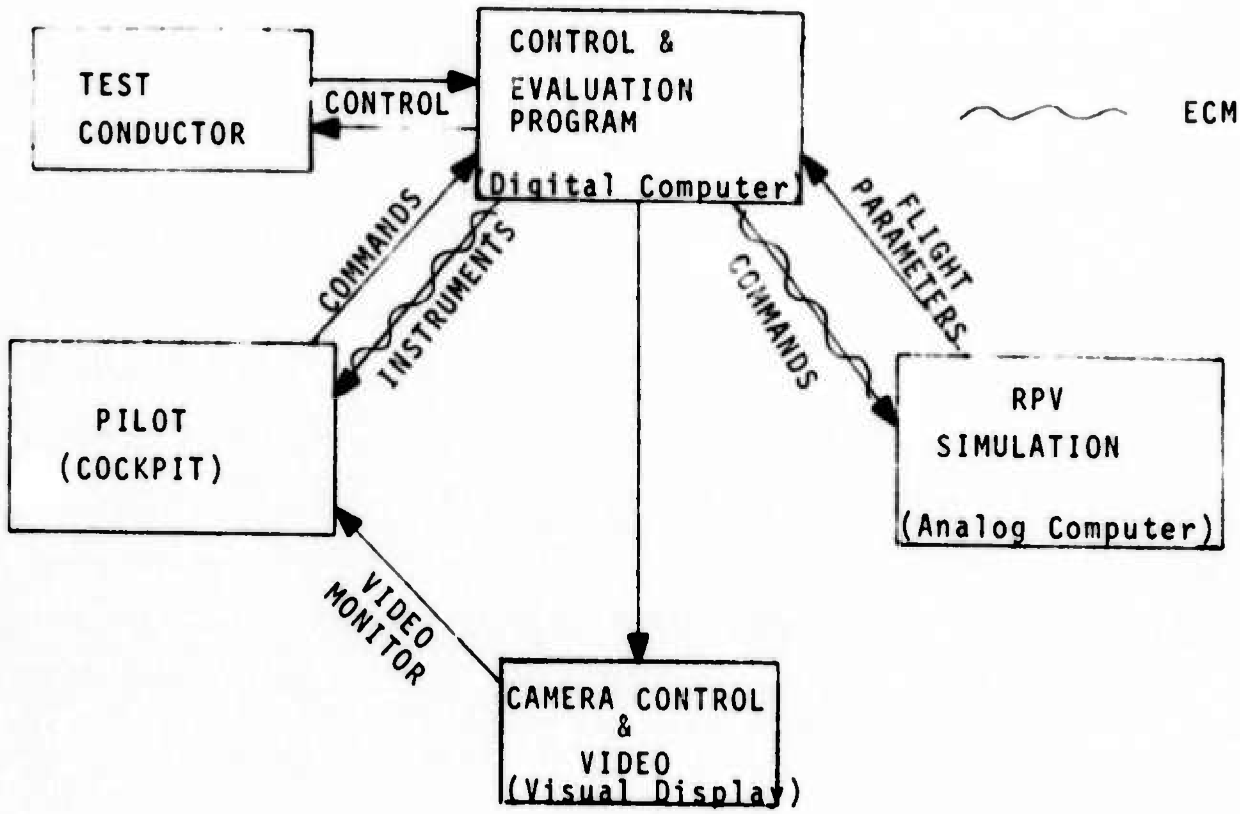
$$\frac{F_x}{M} = \left(\frac{T_{max}}{100\ M}\right) \delta_t + \left(\frac{\rho S C_{x_o}}{2M}\right) U^2 + \left(\frac{\rho S C_{x_\alpha}}{2M}\right) UW + \left(\frac{\rho S C_{x_{\alpha^2}}}{2M}\right) W^2 \tag{2}$$

$$\frac{F_y}{M} = \left(\frac{\rho S C_{Y_\beta}}{2M}\right) UV \tag{3}$$

$$\frac{M_y}{I_y} = \left(\frac{\rho S c\ C_{m_\alpha}}{2 I_y}\right) UW + \left(\frac{\rho S c\ C_{m_{\delta e}}}{2 I_y}\right) U^2\ \delta e + \left(\frac{\rho S c^2\ C_{m_q}}{4 I_y}\right) Uq \tag{4}$$

FIGURE 9

RPV SIMULATION COMPONENTS



$$\frac{M_x}{I_x} = \left(\frac{\rho SbC_{l\beta}}{2I_x}\right) UV + \left(\frac{\rho Sb^2C_{lp}}{4I_x}\right) UP + \left(\frac{\rho SbC_{l\delta a}}{2I_x}\right) U^2\delta a \tag{5}$$

$$\frac{M_z}{I_z} = \left(\frac{\rho SbC_{n\beta}}{2I_z}\right) UV + \left(\frac{\rho Sb^2C_{nR}}{2I_z}\right) UR + \left(\frac{\rho SbC_{n\delta r}}{2I_z}\right) U^2\delta r \tag{6}$$

The quantities in parentheses in the above equations were set on potentiometers by the digital computer and were invariant during each run. The normal variation of these coefficients with Mach number and altitude was ignored for the purposes of these experiments.

The force and moment equations were used for integrating the body angular and linear velocities as follows:

$$\dot{W} = F_z + g\cos\theta\cos\phi + QU \tag{7}$$

$$\dot{U} = F_x - g\sin\theta - QW \tag{8}$$

$$\dot{V} = F_y + g\cos\theta\sin\phi - RU + PW \tag{9}$$

$$\dot{Q} = \left(\frac{M_y}{I_y}\right) \tag{10}$$

$$\dot{P} = \left(\frac{M_x}{I_x}\right) \tag{11}$$

$$\dot{R} = \left(\frac{M_z}{I_z}\right) \tag{12}$$

The following Euler angle equations were implemented for integrating body angles. The usual gimbal - lock restriction prevents loops and the particular analog computer implementation requires that pitch angle remain within plus or minus 90 degrees.

$$\dot{\theta} = Q \cos\phi - R \sin\phi \tag{13}$$

$$\dot{\Psi} = (R \cos\phi + Q \sin\phi)/\cos\theta \tag{14}$$

$$\dot{\phi} = P + \dot{\Psi}\sin\theta \tag{15}$$

The body axes velocities were converted to inertial axes velocities by the following equations:

$$\dot{X} = U(\cos\Psi\cos\theta) + V(\cos\Psi\sin\theta\sin\phi - \sin\Psi\cos\phi) + W(\cos\Psi\sin\theta\cos\phi + \sin\Psi\sin\phi) \tag{16}$$

$$\dot{Y} = U(\sin\Psi\cos\theta) + V(\sin\Psi\sin\theta\sin\phi + \cos\Psi\cos\theta) + W(\sin\Psi\sin\theta\cos\phi - \cos\Psi\sin\phi) \tag{17}$$

$$\dot{H} = U(\sin\theta) - V(\cos\theta\sin\phi) - W(\cos\theta\cos\phi) \tag{18}$$

Simplified flight control systems were implemented to give the operator a choice between a proportional rate and a proportional attitude control system. In the first mode, the operator commands pitch rate and roll rate. In the second mode, he commands flight path angle and bank angle. In both cases, a yaw damper is used in the rudder control system. While in rate mode, the following equations apply:

$$\delta_e = K_1 \quad \delta_{PITCH} + K_Q\, Q \tag{19}$$

$$\delta_a = K_2 \quad \delta_{ROLL} + K_P\, P \tag{20}$$

$$\delta_r = K_3 \quad \delta_{YAW} + \left(\frac{s}{s + 1}\right) K_R\, R \tag{21}$$

While in attitude mode, the following control equations apply:

$$\delta_e = K_4 \quad \delta_{PITCH} + K_Q\, Q + K_\gamma \frac{\dot{H}}{V} \tag{22}$$

$$\delta_a = K_5 \quad \delta_{ROLL} + K_P\, P + K_\phi\, \phi \tag{23}$$

$$\delta_r = K_3 \quad \delta_{YAW} + \left(\frac{s}{s + 1}\right) K_R\, R \tag{24}$$

While all the above equations are simulated on the analog computer, the equations for controlling the video camera are located in the Xerox Data Systems XDS 930 Digital Computer. The video camera can be controlled as if it had 0, 1, 2, or 3 degrees of freedom and with and without zoom. Control of each degree of freedom can be proportional, smoothed, or inertially stabilized. When operated in a direct, proportional mode, the control equations are simply:

$$\Psi_{CAMERA} = \Psi_{COMMAND} \tag{25}$$

$$\theta_{CAMERA} = \theta_{COMMAND} \tag{26}$$

$$\phi_{CAMERA} = 0 \tag{27}$$

When the camera is inertially stabilized, the following equations are used:

$$\Psi_{CAMERA} = \Psi_{COMMAND} - \int\left[R + (P \cos \Psi_{CAMERA} + Q \sin \Psi_{CAMERA}) \tan \theta_{CAMERA}\right] dt \tag{28}$$

$$\theta_{CAMERA} = \theta_{COMMAND} - \int(Q \cos \Psi_{CAMERA} - P \sin \Psi_{CAMERA}) dt \tag{29}$$

$$\phi_{CAMERA} = - \int\left[(P \cos \Psi_{CAMERA} + Q \sin \Psi_{CAMERA}) \sec \theta_{CAMERA}\right] dt \tag{30}$$

When the camera is operated in a smoothed mode, the equations are modified in wash-out circuits as follows:

$$\Psi_{CAMERA} = \Psi_{COMMAND} - \frac{\tau_s s}{\tau_s s+1}\int\left[R + (P \cos \Psi_{CAMERA} + Q \sin \Psi_{CAMERA}) \tan \theta_{CAMERA}\right] dt \tag{31}$$

$$\Theta_{CAMERA} = \Theta_{COMMAND} - \frac{\tau_s s}{\tau_s s+1} \int (Q \cos \Psi_{CAMERA} - P \sin \Psi_{CAMERA})\, dt \qquad (32)$$

$$\Psi_{CAMERA} = - \frac{\tau_s s}{\tau_s s+1} \int [(P \cos \Psi_{CAMERA} + Q \sin \Psi_{CAMERA}) \sec \Theta_{CAMERA}]\, dt \qquad (33)$$

All the above equations are simulated on the analog computer.

SLEW AND ZOOM

The pilot controlled the camera with a sensor control stick mounted on the left console in the cockpit. The stick was capable of two-axis rotation (fore and aft, right and left) and had a two-position switch on top of the grip for zoom control. The zoom switch had a spring return to zero only for zooming out to the target. Consequently, for zooming in, the pilot could pull the switch back and leave it, allowing the sensor to complete zooming in without additional actuation. The maximum slew angles, time constants, zoom rate, degrees of freedom, and stabilization mode were entered into the digital computer program and could be changed between runs from the teletype. Three modes of control could be selected:

0 degrees of freedom - fixed camera

1 degree of freedom - pitch control only

2 degrees of freedom - pitch and yaw control

In each of the control modes the following stabilization modes could operate:

No Stabilization

Smoothing

Pitch Stabilization

Pitch and Roll Stabilization

The stabilization equations were as follows:

$$\Delta\dot{\theta}camera = -Q^* \cos \psi_{camera} + P^* \sin \psi_{camera}$$

$$\Delta\dot{\phi}camera = -(P^* \cos\Psi_{camera} + Q^* \sin \Psi_{camera})/\cos \Theta_{camera}$$

where Ψ_{camera}, Θ_{camera}, and ϕ_{camera} were the respective yaw, pitch, and roll camera angles and P and Q were the body axis, roll and pitch, angular rates.

Yaw stabilization of the camera was examined and found undesirable. This resulted from the fact that yaw stabilization resulted in the camera looking off at a yaw angle after a heading change. There was no immediate cue to the pilot that that had happened and consequently all his translation cues were confused and he had great trouble flying to a point on the terrain.

The simulation video did not include a zoom lens. consequently, zoom was simulated by modifying the camera position to bring it closer to the terrain as the camera "zoomed" out and retract it in response to zoom in. The zoom calculations were normally about the point in the center of the screen but were limited to 3° lookdown whenever the camera was pointed at a higher elevation. The following equations applied:

$$H' = H/\text{zoom}$$

$$X' = X + \frac{1-\text{zoom}}{\text{zoom}} \; H \; \text{ctn}\theta \; \cos\Psi$$

$$X' = Y + \frac{1-\text{zoom}}{\text{zoom}} \; H \; \text{ctn}\theta \; \sin\Psi$$

The normal field of view for the camera system was 30 degrees wide by 24 degrees high. The full zoom position magnified the image by a factor of two to produce a field of view of 15 degrees of width and 12 degrees of height.

Digital Computer

The test conductor initiated each experimental run through a control box. Additional switches allowed him to introduce control transients and accept or reject runs. The digital computer handled the communication between the operator and the vehicle simulation on the analog computer. Intermediate data was stored on magnetic tape for later processing. The analog computer potentiometers were set by the digital computer in response to input aerodynamics and vehicle characteristics. Between runs, the test conductor could change program variables through a teletype located at the cockpit. Scoring and evaluation were also performed in the digital computer.

The flow diagram of the digital computer simulation tasks is shown in Figures 10 and 11.

FIGURE 10

RPV MISSION DIGITAL COMPUTER PROGRAM

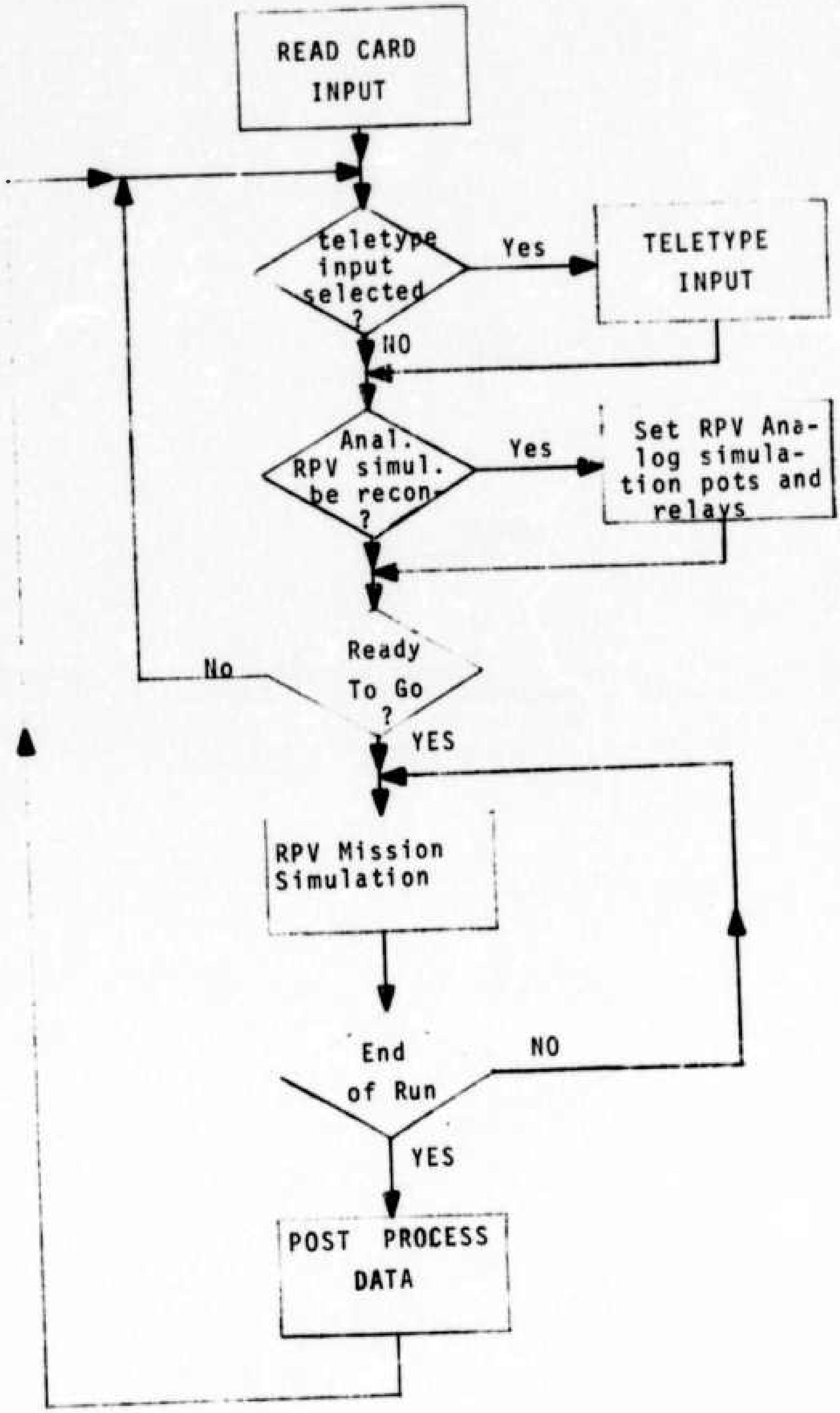
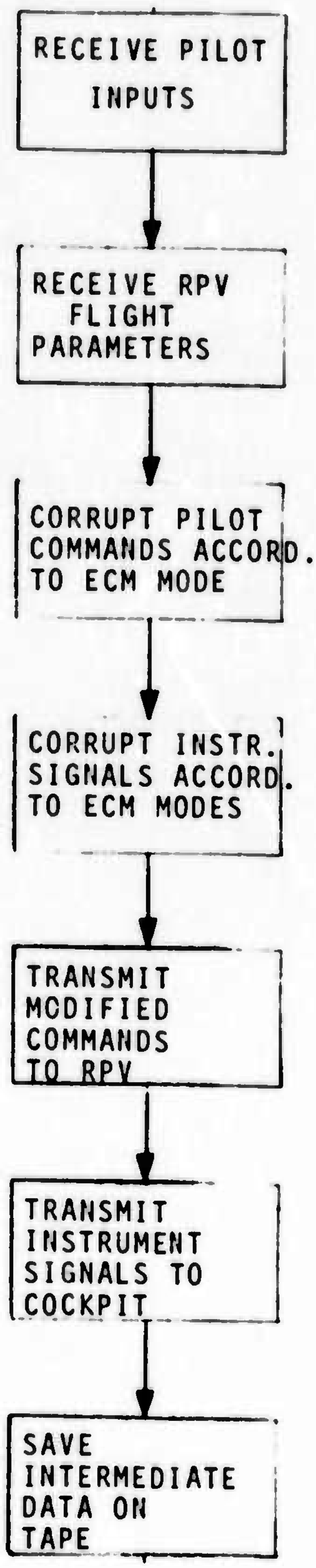


FIGURE 11

RPV MISSION SIMULATION



APPENDIX D

Performance Measurement System for Experiment II, III and IV

Two methods of observing and recording pilot performance were utilized. In both cases most of the results were available after each repetition; however, some of the variables required off-line computer processing or manual processing.

Oscillograph Recording - a multichannel oscillograph recorder was utilized during some runs to generate graphic presentations of the flight profile. Six channels were connected to give a continuous recording of:

- Altitude
- Velocity
- Lateral Displacement from 360° Heading
- Yaw Camera Motion
- Pitch Camera Motion
- Zoom Usage

This method was not operative for all flights and was used only to observe typical flight profiles. This method was not used to generate data for scoring purposes.

Magnetic Tape Recording - the second method utilized was that of recording various variables on magnetic tape. The following variables were recorded for the experiments.

Experiments II and III:

- Time
- Control Stick Commands (Pitch and Roll)

Aircraft Pitch (Angle and Rate)

Aircraft Roll (Angle and Rate)

Induced Elevator Disturbance

Induced Aileron Disturbance

Aircraft Movement (Real-time and Cumulative)

Experiment IV

Time

X and Y Coordinates of Aircraft

Altitude

Down Range and Cross Range From Target to Aircraft Position

Slant Range to Target From Aircraft

Velocity

Aircraft Roll, Pitch and Dive Angles

Relative Camera Zoom Position

Camera Position Angles With Respect to the Aircraft Frame(Yaw and Pitch)

In Experiments II and III the computer generated a printout of the variables mentioned approximately every 45 milliseconds of each run. This printout began two seconds prior to the induced disturbance. From this printout the following performance variables were mannually extracted:

Aircraft Movement

This was a measure of the degree of aircraft movement due to the subject's use of the control stick. To calculate this value a measure was first used of the deviation from straight

and level flight (zero pitch and roll angles). This was obtained by calculating the vector length of the pitch and roll angles.

$$\text{dev} = \text{SQRT}\ (\text{pitch}^2 + \text{roll}^2)$$

This value was calculated during every computation cycle. The more radical the pilot was controlling the aircraft the faster this value would change. The final aircraft movement score was the sum of the differences of these values from one computer cycle to the next multiplied by the length of that cycle (usually 40-50 milliseconds). This summation began when the aircraft anomaly was introduced and continued until the required task was completed.

<u>Completion Time</u>

This was the amount of time from the beginning of the anomaly until straight and level flight was attained. Straight and level flight was determined by the deviation value (Equation 1). In Experiment II, Phases Two and Three, the tolerance was 0 ± 2 degrees for three seconds. In Experiment II, Phase Three this was relaxed to 0 ± 3 degrees for three seconds. Experiment III utilized both a deviation value of 0 ± 2 degrees and required the attitude rate to be within 0 ± 2 deg/sec.

<u>Response Time</u>

This was the elapsed time from the beginning of the perturbation to the pilot's first response to the perturbation. This value was found by observing a time history of the pilot's control stick commands as they related to the onset of the perturbation.

Time to Correct Movement

This was the elapsed time from the beginning of the perturbation until the subject commanded the aircraft toward straight and level flight in both pitch and roll. This value was found by observing the first responses in each dimension (pitch and roll) to see if any control reversals occurred. If there were no reversals the time to correct movement and response time were the same. If control reversals occurred, the time to correct movement was the time from the start of the perturbation until the subject recovered from any control reversals.

Control Reversal

Control reversals were scored by observing the first response in both pitch and roll commands and noting whether or not the commands were correct (in other words, toward straight and level aircraft flight). If not, a pitch and/or roll reversal was noted. No attempt was made to find reversals other than those due to the onset of the anomaly.

For Experiment IV a printout of the variables was provided every 250 milliseconds. The only manual analysis required was the reduction of the zoom data. The other data was reduced by a computer program that generated the following performance variables:

Altitude mean and standard deviation

Heading mean and standard deviation

Airspeed mean and standard deviation

Camera pitch angle mean and standard deviation

Camera yaw angle mean and standard deviation

Correlation between camera pitch and yaw motion

Time of target recognition

Slant range to target at target recognition time

Weapon release time

Weapon release altitude

Slant range to target at weapon release time

Down range and cross range of weapon impact

X and Y coordinates of weapon impact

For further discussion of these variables see Appendix J.

APPENDIX E

General Description of Subjects for Experiments II, III and IV

Two squadrons of qualified Navy pilots were briefed about the general research program, its objectives and experimental procedures. Volunteers were given Form A of Witkin's Embedded Figures Test (EFT) (1971), and administered a demographic questionnaire. Demographic data for each subject group is discussed in separate appendices. An attempt to balance low and high EFT scores and pilot experience levels (low and high) was abandoned as a result of working within the pilots flight operations schedules and availability of the computer.

Homogeneity of qualified Navy pilot sub-group was attempted through a rigorous pre-selection process. This qualifying factor was intended to reduce overall costs and the control problems experienced when dealing with a multitude of experimental variables. Subjects from NAS Miramar were identified through the cooperation of the ONR Office in Pasadena, California. These individuals served not only as subjects but also as contributing experimentors. Willingness to volunteer and availability to participate in this project were important selection criteria. Twenty individuals were utilized to fulfill the entire experimental requirements throughout the full series of tests. Sub-groups of four persons each usually comprised an experimental cluster in a balanced run order.

Prior to initiation of data collection procedures, each subject was thoroughly briefed. This briefing covered the subject's role in the experiment, specific task requirements, use of controls and displays, and experimental procedures. Pre- and post-experiment questionnaires were administered to subjects.

Each subject sat in a ground-based cockpit configured much like conventional aircraft modified for this RPV experiment.

APPENDIX F

EXPERIMENT II

Details of Subjects, Data Reduction Methodology, Experimental Design and Experimental Procedures

<u>Subjects</u>

Six Navy pilots volunteered to participate as subject-experimentors in the first two phase tests. The average age was 27 years with 4.8 years of Navy service and an average of 7.2 years piloting experience. All were college educated, fighter pilots having some simulator experience and some knowledge of research methods. All were in excellent physical condition and had 20/20 vision uncorrected. The average EFT score was 12.8 seconds. When questioned, none had reported experiencing nor were familiar with the phenomena of control reversals.

Four Navy pilots participated in the third phase of this experiment. Average age was 31 years with 9.7 years of Navy service and an average of 9.3 years of pilot experience. Summaries of demographic factors for ten subjects may be found in Table 2.

<u>Experimental Procedure</u>

The experimental procedure for the three phases of experiment II was the same. Each run (unique independent variables configuration) consisted of six repetitions. At the start of each repetition the subject took control of the aircraft at an

Exp.2	Subj.	Age	Yrs. in Navy	Yrs. in College	Yrs. Pilot Exp.	Military Fly. Hrs.	Civilian Fly. Hrs.	Combat Fly. Hrs.	Combat Mission	EFT Scores
Phase 1	1*	30	7	5	10	2000	400	250	130	6.58
	2	25	3	4	3	500	50	0	0	2.33
Phase 2	3	24	2	5	10	310	1500	0	0	12.42
	4	27	5	5	3	1400	600	0	0	30.08
	5	28	6	4	6	1500	100	500	300	21.33
	6	28	6	5	6	1200	20	300	150	4.42
Phase 3	7	29	8	5	7	1700	60	300	150	16.95
	8	37	14	5	14	2600	800	200	70	38.35
	9*	30	7	5	10	2000+	400+	250+	130	6.58
	10	28	10	4	6	1300	0	600	230	15.58
Average		25.8	6.8	4.7	8.0	1451.0	393.0	240.0	116.0	15.462

*Same person.

Table 2
Experiment II

DEMOGRAPHIC DATA SUMMARY
Display Incompatibility

altitude of 6,000 feet and an airspeed of 300 knots. The subject then changed altitude as instructed (within $\pm$ 1,000 foot change). After the subject attained the proper altitude the test conductor introduced an attitude perturbation in pitch and roll. The direction and size of this perturbation was preset by the test conductor prior to each repetition according to a preplanned order which was the same for all subjects, but different for each run. The subject was instructed to recover from this perturbation by returning to straight and level flight. Straight and level flight was defined by preset computer tolerances.

Experimental Design

Experiment II was conducted in three separate phases. Each phase had somewhat different independent variable sets. In spite of this the experimental design for all phases was quite similar.

Phase One

The experimental design for phase one was originally a 3 x 2 x 2 factorial design with balanced run orders for the two subjects. Each subject experienced all combinations of the three variables with six repetitions on each combination. These variables were:

1. Sensor mounting mode three levels (fixed, smoothed, and stabilized).
2. Attitude direction indicator (ADI) two levels (visible and covered).

3. Video heads-up attitude display - two levels (visible and not visible).

This design was reduced to a 3 x 3 factorial after it became obvious that the subjects could not perform the task or performed poorly when no attitude information was available. The new design used the same sensor mounting variable but combined the attitude displays in one variable with three levels (ADI only, heads-up attitude display only, and both ADI and heads-up display).

In this phase the heads-up attitude display was a generated aircraft symbol on the video monitor. This symbol responded in an inside-out mode. This was a plugboard error. It was one of the considerations that led to phase two.

Phase Two

The experimental design for phase two was a 3 x 3 x 2 factorial design with balanced run order. The independent variables were the sensor mounting mode, variable (three levels), the attitude display variable (three levels), and the perturbation time (two levels). The first two variables were the same as in phase one, except that the aircraft symbol responded correctly. The two perturbation times were slow (approximately one second) and fast (approximately 180 milliseconds). Each of the four subjects experienced all combinations of the first two variables with six repetitions on each combination. The perturbation time was held constant for each subject with two subjects experiencing the fast time and two subjects experiencing the slow time.

Phase Three

The experimental design for this phase was a 2 x 2 factorial design with balanced run order. The two independent variables were the video heads-up attitude display mode (artificial horizon and aircraft symbol) and the sensor mounting mode (fixed and stabilized). Each of four subjects was exposed to all four combinations of these two factors with six repetitions on each combination. After the first four runs each subject had two more runs using the two sensor mounting modes with the aircraft symbol attitude display. These two extra runs were introduced to try to identify any possible learning present in the use of the aircraft symbol display. The main reason for trying to find learning on this display was that the pilot/subjects were experienced in responding to an inside-out display (artificial horizon) but not to an outside-in display (aircraft symbol).

Methods for Data Reduction and Analysis

Flight parameters were continuously recorded during the experiment to enable evaluation and consideration of performance measures at leisure. A data reduction program was written that calculated the time to recovery and total aircraft movement. A printout of the significant flight parameters (time, pitch and roll commands, pitch and roll command rates, pitch and roll, pitch and roll rates, indicators of when the perturbation began, measure of aircraft movement and integration of aircraft movement measure) was generated for

the time frame surrounding the perturbation. This printout was reviewed to find the time and direction of the initial pilot response to the perturbation and also to discover any possible control reversals in this response. This portion of the analysis process was not automated due to the lack of an algorithm sufficient to locate these values. The pilot was often maneuvering the aircraft at the time of the perturbation, therefore the pattern of the pitch and roll commands prior to and during the perturbation had to be manually reviewed to pinpoint exactly when the pilot actually responded to the perturbation. It is well-known that writing a computer algorithm to analyze such complex patterns is not a simple or straightforward task.

The data analysis was performed through use of a General Linear Model. This method is being used in lieu of the Factorial Model due to unequal numbers of observations in the design. Unequal observations were a result of data lost in the process of recording on magnetic tape.

Three display configurations were not analyzed. They were the fixed, smoothed, and stabilized TV modes with no attitude display. These combinations were so difficult to fly that the pilots were not able to complete the task, or performed very poorly, so that the specific data collected was essentially useless. The reason for this difficulty centered upon the roll attitude display. In these modes air-

craft attitude was not displayed. The only available feedback was altitude, rate of climb, and the TV camera. With the stabilized camera the pilot received no roll attitude feedback. With the smoothed camera the roll attitude was delayed enough to confuse most pilots. With the fixed camera roll feedback was sufficient for most pilots, however, overall performance was sufficiently degraded as a result of the grossness of this feedback.

APPENDIX G
EXPERIMENT II RESULTS

The results of the experimental phases are shown in Tables 3 through 7. It is emphasized that no data were analyzed which resulted from runs where the subjects had no attitude feedback other than the TV picture. The results of these conditions were so erratic that analysis would have been misleading if not impossible to intepret. In the tables, "A" refers to the attitude display modes; "T" refers to the sensor modes,and "P" refers to perturbation times, when it was an independent variable.

The results include six repetitions for each subject on each display mode. Ten subjects were used. Two on Phase 1, four on Phase 2 (two with long perturbation times and two with short perturbation times) and four on Phase 3. Nine runs (six repetitions each) were analyzed for Phases 1 and 2 for each subject (three sensor modes times three attitude display modes). Six runs were analyzed for Phase 3. Four runs were conducted for combinations of the two attitude modes times the two camera modes plus two runs repeating the aircraft symbol attitude mode with the two camera modes. Repetition of these two combinations explored learning during aircraft symbol attitude mode. The first six pilots were observed to have some difficulty adjusting to that particular display as far as pitch control reversals were concerned.

In Tables 3, 5, and 7, the general factors are noted including F-statistic, degrees-of-freedom and significance

level (if greater than .90) with respect to each continuous variable. The contingency tables along with the chi-squared statistic and degrees-of-freedom are reported for pitch, roll and total control reversals with respect to each factor. The results of testing for significant correlation with run order and repetition order (co-variates) are also reported. These two variables were statistically controlled throughout the analysis. When significant interaction occurred the significance of the main effects is designated by an asterisk indicating that caution should be exercised. The interaction results are reported in Tables 4 and 6.

INTERPRETATION OF TABLES

The interpretation of these tables is best explained by using an example. It may be noted in the body of Table 3, under aircraft movement, there is an F-statistic of 3.375 for the attitude factor, A, with 6 and 97 degrees-of-freedom. This F-statistic is a measure of how much normalized variation (normalized meaning consistent departures from the average value under the different conditions, and not accounted for by normal variation within a given condition) has occurred between the different components of this factor (aircraft symbol, ADI, and both). The smaller the F-statistic the more homogeneous the aircraft movement noted between the components, the larger the F-statistic the larger the effect of these components on aircraft movement.

The degrees-of-freedom determine which F-statistic values are significant. The degrees-of-freedom compensate for differences in sample size and the numbers of levels and factors. The significance of the F-statistic (.99 in our example) implies that if these three levels (i.e., three attitude display modes) had no real effect on this variable (aircraft movement) then 99% of the time aircraft movement scores generating a smaller F-statistic would be expected.

The conclusion is that this F-statistic did not result from that 1% random occurrence but was due to a real difference in the effect of these levels on those subject's performance with respect to aircraft movement. The direction of these differences is found by looking at the actual average values associated with these conditions. In this case the averages are:

A_0 = 2.679 deg.sec.

A_1 = 1.945 deg.sec.

A_2 = 1.956 deg.sec.

As can be seen the A_1 and A_2 averages are virtually the same whereas the A_0 average is considerably larger. The size of this difference is deemed significant by using a Multiple Range Test (Duncan's Multiple Range Test in this case). It indicates which averages are significantly different. This is done by looking at the pooled standard deviation (sort of an average of the standard deviations under each condition) and discerning if the difference between specific averages is larger than would be expected by chance.

TABLE 3 .(page 1 of 2)

Results of Experiment II Phase I - Continuous Variables

A = Attitude display modes - 3 Levels

A_0 = Acft** symbol - responds as Artficial Horizon.
A_1 = ADI.
A_2 = Both Acft.* symbol(A_0) and ADI(A_1).

T = TV camera modes - 3 Levels

T_0 = Fixed to Airframe.
T_1 = Smoothed.
T_2 = Stabilized.

Factor	Degrees of Freedom	Time to Respond F-Statistic	Time to Respond Sig. Level	Time to Correct Move F-Statistic	Time to Correct Move Sig. Level	Time to Completion F-Statistic	Time to Completion Sig. Level	Aircraft Movement F-Statistic	Aircraft Movement Sig. Level
A	(6,97)	*2.83(1)	.975	.738	N.S.	3.64(2)	.995	3.375(2)	.99
T	(6,97)	*3.699(1)	.995	.574	N.S.	.963	N.S.	.886	N.S.
TA	(4,97)	*3.07(1)	.975	.443	N.S.	.968	N.S.	1.123	N.S.
Co-Variates	(2,97)	.194	N.S.	.941	N.S.	1.08	N.S.	2.163	.90

(1) - Interaction detailed results reported in table A_4.
(2) - A_0 significantly greater than A_1 and A_2.

** - Aircraft

Table 3 (Page 2 of 2)

Control Reversal Results

Frequency Tables			x^2 Statistic - 2 d.f.	Significance
Total Reversals				
A_0	A_1	A_2		
13	3	7	$6.6^{(1)}$	.95
T_0	T_1	T_2		
9	8	6	.61	N.S.
Pitch Reversals				
A_0	A_1	A_2		
5	1	4	4.609	N.S.
T_0	T_1	T_2		
4	3	3	.677	N.S.
Roll Reversals				
A_0	A_1	A_2		
8	2	3	$4.77^{(1)}$	.90
T_0	T_1	T_2		
5	5	3	1.7	N.S.

(1) A_0 significantly more reversals

TABLE 4

Detailed Results of Experiment II - Phase 1

Time to Respond

Average times (seconds) under the various combinations of TV camera modes and attitude display modes.

	A_o	A_1	A_2
T_o	$.589_2$	$.53_2$	$.526_1$
T_1	$.6325_3$	$.582_2$	$.633_3$
T_2	$.6683_4$	$.7425_5$	$.532_1$

Averages with the same subscript are not significantly different (.95 level - Duncan's Multiple Range Test)

Group	Mode Combinations
1	A_1T_o, A_2T_o, A_2T_2
2	A_oT_o, A_1T_1
3	A_oT_1, A_2T_1
4	A_oT_2
5	A_1T_2

Table 5

Results - Experiment II Phase 2 - Continuous Variables

A = Attitude Display Modes - 3 Levels - (A_o = Acft. Symbol)
(A_1, A_2 as in Phase 1)

T = Sensor Mounting Modes = 3 Levels - Same as Phase 1

P = Perturbation Times - 2 Levels (P_o = Long Pert.; P_1 = Short Pert.)

Factors	Degrees of Freedom	Time to Respond		Time to Correct Move		Time to Completion		Aircraft Movement	
		F-Stat.	Sig.Level	F-Stat.	Sig.Level	F-Stat.	Sig.Level	F-Stat.	Sig.Level
A	(14,194)	1.42	N.S.	*5.031[2]	.9999	3.369[3]	.9995	*3.595[2]	.9995
T	(14,194)	.779	N.S.	*2.403[2]	.995	1.250	N.S.	*2.133[2]	.975
P	(13,194)	1.183	N.S.	*2.733[2]	.995	2.091[4]	.975	*2.364[2]	.99
[1]AT) [1]AP) [1]TP)	(12,194)	.787	N.S.	*2.623[2]	.995	1.440	N.S.	*2.371[2]	.995
ATP	(4,194)	.795	N.S.	*2.384	.95	.943	N.S.	*2.616	.95
Covariates	(2,194)	.8696	N.S.	2.387	.90	1.230	N.S.	5.417	.995

1. 2nd Order Interactions Tested Together
2. Detailed results in Table 5.
3. A_o significantly greater than A_1 and A_2.
4. P_1 significantly greater than P_o.

Table 5 continued

CONTROL REVERSAL RESULTS
(P has no effect)

	Frequency Tables			X^2 Statistic - 2 d.f.	Significance
Total Reversals	A_0	A_1	A_2		
	36	14	8	22.5[1]	.999
	T_0	T_1	T_2		
	16	21	21	.86	N.S.
Pitch Reversals	A_0	A_1	A_2		
	8	4	6	1.33	N.S.
	T_0	T_1	T_2		
	3	7	8	2.33	N.S.
Roll Reversals	A_0	A_1	A_2		
	28	10	2	26.6[1]	.999
	T_0	T_1	T_2		
	13	14	13	.05	N.S.

(1) A_0 significantly more reversals.

Table 6

Detailed Results of Experiment II - Phase 2

Time to Correct Movement

Average times (seconds) under various combinations of perturbation time, TV camera modes and attitude display modes

P_o

	A_o	A_1	A_2
T_o	2.15_8	$.651_{1,2,3}$	$.599_{1,2}$
T_1	1.69_7	$.641_{1,2,3}$	$.53_1$
T_2	1.1_6	$.817_4$	$6.85_{2,3}$

P_1

	A_o	A_1	A_2
T_o	$.833_4$	$.658_{1,2,3}$	$.825_4$
T_1	$.976_5$	$.657_{1,2,3}$	$.743_{3,4}$
T_2	1.09_6	$.532_1$	$.838_4$

Averages with same subscript are not significantly different (.95 level Duncan's Multiple Range Test).

Group	Mode Combinations
1	P_o - A_2T_1, A_2T_o, A_1T_1, A_1T_o; P_1 - A_1T_2, A_1T_1, A_1T_o
2	P_o - A_2T_o, A_1T_1, A_1T_o, A_2T_2; P_1 - A_1T_1, A_1T_o
3	P_o - A_1T_1, A_1T_o, A_2T_2; P_1 - A_1T_1, A_1T_o, A_2T_1
4	P_o - A_1T_2; P_1 - A_2T_1, A_2T_2, A_2T_o, A_oT_o
5	$P_1A_oT_1$

Group	Mode Combinations
6	$P_oA_oT_2$, $P_1A_oT_2$
7	$P_oA_oT_1$
8	$P_oA_oT_o$

Table 6 Cont'd.

Aircraft Movement

Average values (degree-seconds) under various combinations of perturbation time, TV camera modes, and attitude display modes

	P_o		
	A_o	A_1	A_2
T_o	7.09_9	1.9_1	1.95_1
T_1	4.42_7	2.03_1	1.88_1
T_2	$2.73_{2,3}$	2.05_1	$2.96_{2,3,4}$

	P_1		
	A_o	A_1	A_2
T_o	$3.38_{4,5,6}$	2.61_2	$3.22_{4,5}$
T_1	4.15_7	$3.58_{5,6}$	$3.05_{3,4}$
T_2	4.83_8	3.67_6	$3.16_{4,5}$

Averages with same subscript are not significantly different (.95 level- Duncan's Multiple Range Test).

Group	Mode Combinations
1	P_o - A_2T_1, A_2T_o, A_1T_o, A_1T_2, A_1T_3
2	P_o - A_oT_2, A_2T_2; P_1 - A_1T_o
3	P_o - A_oT_2, A_2T_2; P_1 - A_2T_1
4	P_o - A_2T_2, P_1- A_2T_1, A_2T_2, A_2T_o, A_oT_o
5	P_1 - A_2T_2, A_2T_o, A_oT_o, A_1T_1
6	P_1 - A_oT_o, A_1T_1, A_1T_2
7	P_1 - A_oT_1, $P_oA_oT_1$
8	$P_1A_oT_2$
9	$P_oA_oT_o$

Table 7

Results of Experiment II Phase 3 - Continuous Variables

A = Attitude Display Modes — A_o = Artificial Horizon; A_1 = Acft. Symbol

T = Sensor Mounting Modes — T_o = Fixed to Airframe; T_1 = Completely stabilized

Factors	Degrees of Freedom	Time to Respond F-Stat.	Time to Respond Sig.Level	Time to Correct Move F-Stat.	Time to Correct Move Sig.Level	Time to Complete F-Stat.	Time to Complete Sig.Level	Aircraft Movement F-Stat.	Aircraft Movement Sig.Level
A	(2,138)	2.07	N.S.	3.076[2]	.95	.506	N.S.	.664	N.S.
T	(2,138)	1.58	N.S.	.000	N.S.	.514	N.S.	.691	N.S.
AT	(1,138)	2.856[1]	.90	.000	N.S.	.982	N.S.	1.555	N.S.
Covariates	(2,138)	1.008	N.S.	.974	N.S.	4.367	.975	2.49	.90

1) AT_{00}, AT_{11} significantly less than AT_{10}, AT_{10}

2) A_1 significantly greater A_o

Table 7 - Cont'd.

Control Reversal - Results

RA_1 - Repetition of A_1

	Frequency Tables			χ^2 Statistics - 2 d.f.	Significance
Total Reversals	A_o	A_1	RA_1		
	29	27	29	.094	N.S.
	T_o	T_1			
	41	44		.106	N.S.
Pitch Reversals	A_o	A_1	RA_1		
	20	2	6	18.1^1	.995
	T_o	T_1			
	15	13		.071	N.S.
Roll Reversals	A_o	A_1	RA_1		
	9	25	23	8.00^2	.975
	T_o	T_1			
	26	36		1.61	N.S.

1) A_o significantly larger than A_1 or RA_1

2) A_o significantly smaller than A_1 or RA_1

DISCUSSION OF RESULTS

Phase 1

Phase 1 consisted of three attitude displays (inside-out aircraft symbol, ADI, and both ADI and inside-out aircraft symbol) and three sensor mounting modes (fixed, smoothed and stabilized). The camera downlook angle was fixed at 15° and the perturbation speed was fixed at one second. Tables 3 and 4 indicate the results of the analysis.

Significant interaction with respect to response time is detailed in Table 4. It may be noted that, in general, higher values (poorer results) were noted with T_2 (stabilized mode) and lower values with T_0 (fixed mode) indicating that the lack of or delay in TV picture movement (stabilized or smoothed, respectively) contributed to longer response times. This outcome, however, was not consistently true. Other interpretations of the interaction values are not immediately obvious. It should be noted that no significant effects were noted with this variable during Phase 2 of this experiment.

The aircraft symbol that responded in an inside-out manner contributed significantly to longer completion times and more aircraft movement. It may be that relative unfamiliarity with a heads-up display as opposed to the conventional ADI could have contributed to these results. Some improvement with experience was noted with respect to aircraft movement scores. The aircraft symbol also contributed to a greater total number of control reversals along with more

roll reversals. Display unfamiliarity again may be a possible reason for this outcome.

Phase 2

Phase 2 contrasted three attitude displays (outside-in aircraft symbol, ADI, and both outside-in aircraft symbol and ADI), three sensor mounting modes (fixed, smoothed, and stabilized) and two perturbation times (slow, one second; fast, 180 milliseconds). Camera downlook angle was 7.5°. Tables 5 and 6 indicate the numerical results of the analysis.

No significant results were noted with respect to response time, an outcome differing from Phase 1.

Time to correct movement was affected by all variables (i.e., interaction was significant). Some improvement was noted with increased experience. Generally better performance was demonstrated in the experiment with the ADI than with the aircraft symbol. TV modes and perturbation times had an effect on the correct movement times, however, this effect was not consistent nor readily interpretable.

Completion times were significantly longer with the aircraft symbol only. Unfamiliarilty and confusing background probably explain this result. Perturbation duration times also contributed to significantly different completion times. Completion times with the <u>short</u> perturbation were longer than with the <u>long</u> perturbation. The effects of the pertur-

bation could be a result of the sudden onset of the perturbation eliciting a surprise reaction from which the subject takes longer to recover.

Significant interaction was noted with respect to aircraft movement. Aircraft movement here is an inverse measure of consistency of control. In general, both the short perturbation and aircraft symbol contributed to more aircraft movement. There was a tendency for increase in background motion to improve aircraft controlability (decrease the aircraft movement score). These results agree partially with the results for completion time. The sensor mounting mode effects could indicate that the subject was confused, when there was not a one-to-one relationship between the heads-up attitude display and the video picture.

The aircraft symbol contributed to significantly more total control reversals and more roll reversals. The most obvious reason for this was subject familiarity with the ADI type instrument.

Phase 3

Phase 3 consisted of two heads-up attitude displays (outside-in aircraft symbol and inside-out artificial horizon) and two sensor mounting modes (fixed and stabilized) the camera downlook angle was 7.5°. The perturbation time was 180 milliseconds. Numerical results of analysis are shown in Table 7.

Some interaction was noted with respect to time to respond. When both the heads-up attitude display and the sensor mounting were in the same type mode [in other words, inside-out (artificial horizon and fixed) or outside-in (aircraft symbol and stabilized)] reaction time was decreased over conflicting modes.

The artificial horizon contributed to significantly better times to correct movement. This was mainly due to the less drastic pitch control reversals with this mode.

Significant learning was noted with respect to completion times (i.e.,completion time decreased with experience on the simulator). Some learning was noted with respect to aircraft movement scores so that aircraft movement scores decreased as experience on the simulator increased.

No significant differences were noted in the total number of control reversals, but there were significantly more pitch reversals with the artificial horizon and more roll reversals with the aircraft symbol. There was no apparent decrease or increase in control reversals (pitch, roll, or total) as experience with the aircraft symbol increased.

APPENDIX H

Details of Experiment III Subjects, Methodology, and Design

Two pilot-subjects, average age 27.5 years (See Table 8 for subject data), were exposed to 36 trials (6 repetitions for 6 combinations) each in a balanced run order 2 x 3 factorial design. The subjects were launched at 1000 feet and instructed to fly the aircraft to 500 foot altitude, maintaining this altitude and an airspeed just above 136 knots. Subjects were also instructed to look for ground targets. Altitude and airspeed performance were not scored in this experiment since the particular controls in use would maintain fairly consistent flight profiles across subjects. Once a stable flight condition had been reached an attitude perturbation (180 milliseconds) disturbing pilot control was introduced to the aircraft. The subject's task was to recover control and stabilize the craft while maintaining altitude, direction, and speed parameters. The study compared performance variables for three heads-up displays each under two different camera mounting modes. Dependent variables for performance measurement were the same as for experiment two. Independent variables were sensor mounting (same as experiment two, phase three, fixed and stabilized) and heads-up attitude display. Three heads-up attitude displays were presented to subjects. They were: aircraft symbol (outside-

Subject	Age	Yrs.In Navy	Yrs. In College	Yrs.Pilot Exp.	Mil.Flying Hours	Civ.Flying Hours	Combat Fly.Hrs.	Combat Missions	EFT Scores
11	28	7	4	6	1650	0	400	160	22.75
12°	27	5	5	8	1400	600	0	0	30.08
Average	27.5	6	4.5	7	1525	300	200	80	26.41
Average Exp.2+3	26.08	6.7	4.7	7.83	1463	377.5	233	110	17.3

° Same as S #4 Exp. 2

Table 8

Demographic Data Summary

Experiment 3

in), artificial horizon (inside-out) and combination. Here the combination display is the same as referenced earlier wherein the artificial horizon moves in roll only and the aircraft symbol moves in pitch only.

In effect, experiment III was different from experiment II, phase three in two ways. The aircraft was launched and flown at much lower altitudes. A new heads-up attitude display was generated and compared to the two previously used displays.

APPENDIX I

Experiment III

Results

The results of the experiment revealed that the combination display decreased total control reversals (See Table 9).

There was a significant increase of roll reversals with the aircraft symbol. The inside-out presentations of roll attitude, artificial horizon, and combination display were superior.

For overall time-to-respond, significant differences in performance were obtained. The aircraft symbol resulted in improved performance ($p > .995$). (See Table 10 for results.)

Significant learning ($p > .95$) was demonstrated in the subject's ability to control the aircraft. Aircraft movement scores were also significantly improved within runs yielding evidence of significantly increased performance with a particular display. For performance with respect to efficiency of control (aircraft movement) further significant results were obtained. At the .95 level the artificial horizon attitude display was shown to be significantly less desirable than the other attitude indicators. At the same time a fixed camera yielded the best performance ($p > .90$) when compared to the stabilized mode.

TABLE 9

Control Reversals

Results

Frequency Tables			X^2-Statistic (2 d.f.)	Significance
Total Reversals				
A_o	A_1	C*		
19	13	5	3.6	NS(.85)
(T_o)Fixed	(T_1) Stab.**			
13	15		.14	N.S.
Pitch Reversals				
A_o	A_1	C		
6	4	4	.57	N.S.
Fixed	Stab.			
6	8		.29	N.S.
Roll Reversals				
A_o	A_1	C		
4	9	1	7.0	.95
T_o(Fixed)	T_1(Stab)			
7	7		0.0	N.S.

* Attitude Displays

A_o = Artificial Horizon

A_1 = Aircraft Symbol

C = Combination

** Camera Modes

Fixed = Fixed to Airframe

Stab = Stabilized in pitch and roll.

TABLE 10

RESULTS EXPERIMENT III Continuous Variables

A= Attitude Display Modes -3 levels T=T.V. Camera Modes - 2 levels

Factors	Degrees of Freedom	Time to Respond		Time To Correct Movement		Time to Complete		Aircraft Movement	
		F-Stat.	Sig. Level	F-Stat.	Sig. Level	F-Stat.	Sig. Level	F-Stat.	Sig. Level
A	3,64	4.64	.995[1]	1.22	N.S.	.741	N.S.	2.81	.95[2]
T	4,64	1.61	N.S.	.539	N.S.	.337	N.S.	2.68	.90[3]
AT	2,64	.664	N.S.	.793	N.S.	.463	N.S.	2.11	N.S.
Covariates	2,64	.745	N.S.	.003	N.S.	1.54	N.S.	3.54	.95[4]

1. Aircraft symbol had significantly fastest times -

Display	Reaction Time
Aircraft Symbol	.464 sec.
Artificial Horizon	.594 sec.
Combination Display	.608 sec.

2. Artificial Horizon had higher movement -

Display	Average Movement Values
Artificial Horizon	11.8 deg. sec.
Combination	7.5 deg. sec.
Aircraft Symbol	7.4 deg. sec.

3.

Display	Average Movement
Fixed Camera	7.41 deg. sec.
Stabilized Camera	10.4 deg. sec.

4. Learning Significant - Aircraft movement decreases with experience in general.

Run = 1, 2, . . ,6
Rep = 1, 2, . . ,6
6 Repetitions for each Run.

Aircraft Movement = 8.9 deg.sec. -.495 deg.sec. x Run No. -1.095 deg.sec.xRepetition No.

APPENDIX J

Experiment IV
Total Strike Mission Experiment
Details of Subjects, Methodology, and Experimental Design

Subjects

Eight qualified Naval pilots participated as subject-experimentors as volunteers. Average age was 31 years with an average of 7.6 years as pilots. Refer to Table 11 for demographic data. The subjects averaged nine years of Naval experience. They indicated considerable experience with the typical tasks required of them. Considerable demographic data and commentary concerning the experiment were collected, however, not reduced. These data were not considered vital to the purpose at hand, and were used only when special attention to a particular performance was required.

Experimental Design

A 3 x 2 x 2 factorial design with balanced run order was used for this experiment. There were four repetitions within each run for each subject. The three independent variables were the task, attitude display/camera mode, and zoom. A brief description of each follows.

Task: Three tasks were presented to the subjects. The original experiment had called for contrasting slew and no slew of the TV camera. There was also an interest in contrasting the use of "smart" and "dumb"

TABLE 11

Demographic Data Summary
Experiment IV

Subject	Age	Yrs. In Navy	Yrs. In College	Yrs. Pilot Experience	Mil. Fly Hours	Civ. Fly Hours	Combat Fly Hrs.	Combat Missions	EFT Scores
13	24	2	5	2	300	40	0	0	12.22
14	28	6.5	4.5	5	1637	0	400	153	32.6
15	33	11	4	8	1850	0	100	60	31.36
16	24	2	4	4	300	600	0	0	32.9
17	30	9	4	9	2100	150	300	140	24.25
18	41	16	4	15	2900	50	0	0	27.58
19	29	5	6	5	1200	4	300	140	9.6
20	38	20.5	6	13	3900	0	250	150	22.75
Averages	31	9	4.7	7.6	1780	105.5	170	80	24.16
Averages Exp. II, III, IV	28.05	7.6	4.675	7.74	1590	268.7	208	98	20.04

weapons. This was to be done by assuming the "smart" weapons could go to the point on the ground at which the camera was looking at release time. The "dumb" weapons would continue on the flight path of the aircraft after release. A preliminary inspection of these two factors showed that they were inter-related in that the "smart" weapon with no camera slew was like the "dumb" weapon without camera slew as the aircraft and camera were always pointing in the same direction except for a downlook bias. Therefore, the subjects were told to perform three tasks.

The first task involved no slew and the subject was required to fly the aircraft so that the reticle was on the target. Under this task the reticle displayed the position at which the aircraft nose was pointing. Engineering tests on this task demonstrated the need for different sensor angles for the two mounting modes. It was noted that a -7.5° angle with the fixed mode created an unrealistic bias on the position of the bulls-eye (near the top of the screen) whereas a 0° downlook put the bulls-eye in the center of the screen wich was much easier for sighting, particularly in a dive. The 0° downlook for the stabilized mode was unrealistic due to the fact that very little of the terrain could be seen. Minus 7.5° was chosen because a larger angle forced the bulls-eye (i.e., indicator of aircraft nose) off the

screen in a shallow dive. In the other two tasks the angle could be adjusted by the subjects through use of slew control. The first task was comparable to having either a "dumb" or a "smart" weapon without slew. The second task was similar to having a "dumb" weapon with slew control available for target search. In this task the bulls-eye again indicated the aircraft nose pointing angle with respect to the sensor. The third task simulated a "smart" weapon that would, upon release, fly to the ground point at which the sensor was directed. In this task the bulls-eye remained fixed at the center of the screen as it indicated where the camera was pointing. The subject could accomplish this task by flying the aircraft to the target or by flying the aircraft in the vicinity of the target then using the slew controls to center the sensor on the target and then release the weapon.

All three tasks involved putting the gunsight reticle on the target at weapon release. Both body-fixed and sensor-fixed gunsights were simulated. The body-fixed sight would typically be required for "dumb" weapons such as unguided bombs, rockets, guns, etc. The sensor-fixed sight would typically be associated with "smart" weapons such as television or infrared guided bombs, guided rockets, etc. The sensor-fixed sight remained stationary on the video monitor at all times, while the body-fixed sight moved

in compensation for sensor motions with respect to the airframe. For example, if the sensor was depressed five degrees, the sight rose five degrees on the monitor. This motion could be in response to pilot slewing commands or sensor stabilization commands.

Figure 12A shows the video image the pilot sees as he approaches the target. The target is represented by the black square with the white center spot. Figures 12B and 12C show the "outside-in" aircraft symbol in conjunction with the gunsight. The aircraft symbol is depressed from the center of the screen due to a 30° pitch down attitude. The symbol is rolled ten degrees to represent a ten degree right bank.

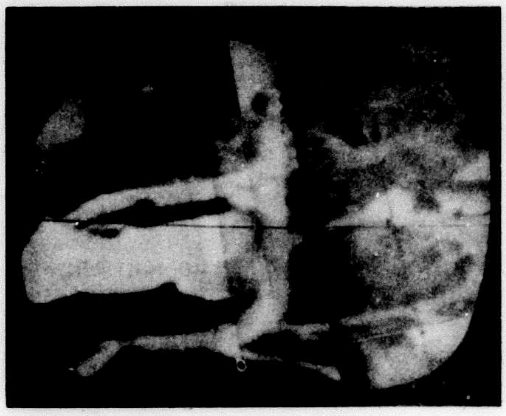
In Figure 12B the reticle is shown as aligned with the aircraft nose. Consequently, since the camera is nominally biased down the reticle appears 7.5 degrees above the horizon on the video monitor since it indicates the relative angle between the camera and the RPV's nose. In the vehicle fixed gunsight mode, the symbol moves in response to the subject's sensor control motions or stabilization commands. The symbol always represents the orientation of the vehicle relative to the camera. The gunsight in Figure 12C is aligned with the camera and consequently remains centered even during camera slewing. This type of gunsight is more typical of "smart" weapons that only need to be "shown" the target. Figure 12D

illustrates the artificial horizon or "inside-out" symbol. Notice that in comparison with the aircraft symbol of Figure 12C it is located high on the screen to indicate a 30° dive and that the 10° right wing down results in a horizon which is right side high. Figure 12E illustrates the composite symbol. The horizon is retained for roll indication and pivots about the center of the screen. The aircraft symbol always appears wing level but otherwise shows pitch attitude. The two different gunsight modes are available with any of three attitude symbols.

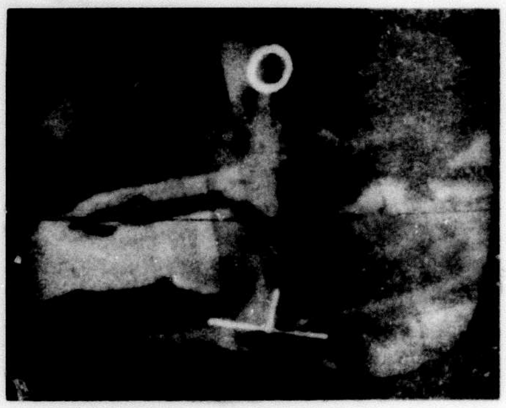
Attitude Display Sensor Mounting Mode: In the previous experiments results demonstrated certain conclusions about compatability of displays. In particular, the results showed that efficient flight control is improved with a fixed sensor mode and the combination attitude display. Also, it was noted that if a stabilized sensor was needed that the aircraft symbol was the better attitude display. In this experiment a contrast was desired between the fixed and stabilized modes for target acquisition and attack. The previous results dictated the attitude displays used. Sensor angles of 0.0° for the fixed mode and -7.5° for the stabilized mode were used. The reasons for this are explained in the previous section.

Figure 12

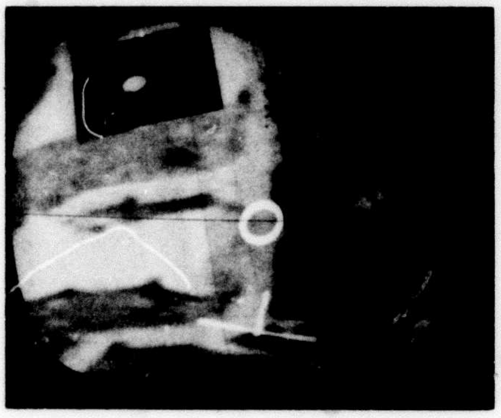
Examples of Video Picture and Different Heads-Up Attitude Displays



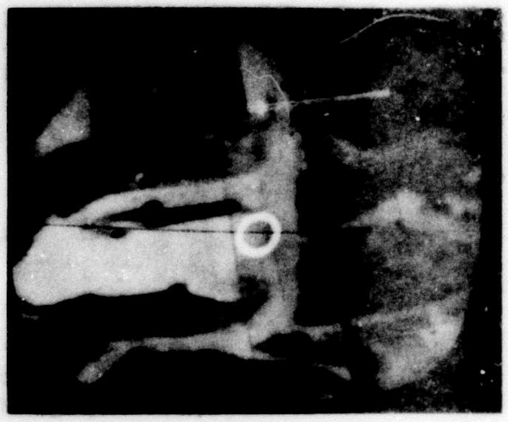
12A Video Picture



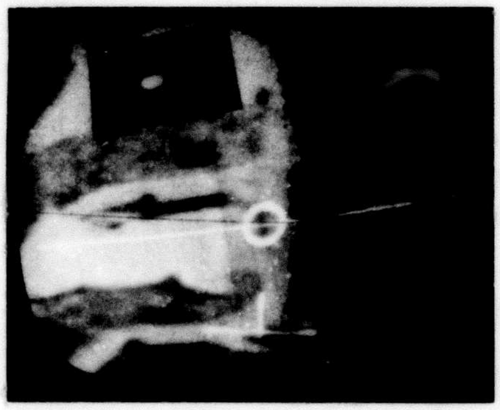
12B Aircraft Symbol with "dumb" weapon



12C Aircraft Symbol with "smart" weapon



12D Artificial horizon with "smart" weapon



12E Combination Display with "smart" weapon

Zoom: This factor had two levels which were the presence or absence of a zoom capability on the camera. No specific requirements were given to force the use of zoom when available.

Dependent Variables

For scoring purposes the mission was separated into three phases.

Phase One - Enroute:

This started ten seconds after launch and continued until twenty-five seconds after launch. During this phase the subjects were scored on maintenance of altitude, velocity, and heading. The scores recorded were the mean and the standard deviation of attitude in feet, heading in degrees and velocity in feet per second (fps).

Phase Two - Target Search: This phase started twenty-five seconds after launch and lasted until the target recognition button was pressed. The variables recorded here were the time at target recognition and the slant range from aircraft to target at target recognition. During this period a recording of the use of slew was made. The means and standard deviation of the camera pitch and yaw angle movements were calculated along with the correlation between sensor pitch and yaw control.

Phase Three - Attack: The scores for this phase involve the weapon release data. These were the weapon release time, slant range to target at weapon release, down range, cross-range, and miss distance of the weapon impact point.

A recording of the use of zoom was kept during the mission and the number of seconds the camera was zoomed out was recorded.

The above variables were recorded for each repetition (4 repetitions per run). The error mean square (EMS) of these values were also calculated for the four repetitions in each run. These EMS scores were used mainly to detect consistency in the targeting phase (search and attack) as the impact scores were sometimes biased due to alignment of the simulator map and due to the use of different targets on different runs.

The data analysis was performed through the use of the General Linear Model due to unequal numbers of observations. This came about through the subject's failure to hit target at times, his missing the target recognition button, and programming parameters being mis-initialized. Analysis was also performed using multiple correlation techniques to try to discover inter-relationships between behavior variables (e.g. zoom use, slew use) and performance variables (e.g. miss distance). A program was written for this purpose to enable computation on multivariate observations with missing values of some but not all the variables.

APPENDIX K
Experiment IV

Results

The results of the analysis of variance on the general linear model are shown in tables 12 and 13 . Table 12 lists the results for the actual variable values that were recorded for each repetition. Here the slew and zoom use measures are not analyzed as they were zero under certain conditions.

Significant results on these variables imply that there were differences in the actual performance of the subjects under the various conditions. For example, under "heading mean" the availability or non-availability of zoom was significant, in favor of availability of zoom. This means that when zoom was available the subjects maintained headings significantly closer to 360°. This significance is not readily interpretable and could be due to random chance. See Appendix G for further details on interpreting the tables.

Table 13 shows the results using the square root of the error mean square (EMS) of the actual variables. EMS here is a measure of how much variation there was of the variables over four repetitions under identical conditions. In other words, it is a measure of the consistency of subjects performance on the particular variable. Significance here implies a difference in consistency of performance (not necessarily better or worse) on the referenced variable. For example, under target recognition slant range EMS there was some small significance with respect to the zoom factor. The availability of zoom resulted in increased EMS on the target

A= Attitude Display/Sensor Mode
A_0=Combination Attitude Display/Fixed Sensor
A_1= Aircraft Symbol Attitude Display/Stabilized Sensor
Z = Zoom
Z_0= No zoom available
Z_1= Zoom available

T=Task
T_0=No Sensor Slewing,"Dumb Weapon
T_1=Sensor Slewing "Dumb Weapon"
T_2=Sensor Slewing "Smart Weapon"

		Heading Mean	Heading Std.Dev.	Altitude Mean	Altitude Std.Dev.	Velocity Mean	Velocity Std.Dev.	Target Recog. Time	Target Recog. Slant Range	Weapon Release Time	Weapon Release Altitude	Weapon Release Slant Range	Weapon Impact Down Range	Weapon Impact Cross Range
A	F	.09	.14	.22	.177	.637	.155	.147	.488	.016	.27	1.055	.398	.088
	d.f.	1,180	1,180	1,128	1,128	1,128	1,128	1,154	1,154	1,165	1,165	1,165	1,165	1,165
	Sig	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Z	F	4.52	.114	.07	.099	.002	.1	.654	.498	.014	.048	.053	.008	.039
	d.f.	1,180	1,180	1,128	1,128	1,128	1,128	1,154	1,154	1,165	1,165	1,165	1,165	1,165
	Sig	.975*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
T	F	1.65	.116	.541	.071	.023	.071	.212	.205	.018	1.36	.063	.088	.039
	d.f.	2,180	2,180	2,128	2,128	2,128	2,128	2,154	2,154	2,165	2,165	2,165	2,165	2,165
	Sig	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
AZ	F	2.82	.986	.028	.071	.005	.081	.044	.021	.031	.231	.053	.021	.03
	d.f.	1,189	1,180	1,128	1,128	1,128	1,128	1,154	1,154	1,165	1,165	1,165	1,165	1,165
	Sig	.90*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
AT	F	.614	.364	.318	.048	.215	.077	.118	.238	.043	.142	.055	.233	.046
	d.f.	2,180	2,180	2,128	2,128	2,128	2,128	2,154	2,154	2,165	2,165	2,165	2,165	2,165
	Sig	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
ZT	F	.575	.05	.332	.032	.075	.079	.105	.110	.095	.02	.064	.032	.028
	d.f.	2,180	2,180	2,128	2,128	2,128	2,128	2,154	2,154	2,165	2,165	2,165	2,165	2,165
	Sig	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
AZT	F	.736	.21	.131	.059	.143	.077	.085	.162	.072	.015	.063	.004	.083
	d.f.	2,180	2,180	2,128	2,128	2,128	2,128	2,154	2,154	2,165	2,165	2,165	2,165	2,165
	Sig	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

*Zoom factor effect on Heading mean Z_0=.567 degrees; Z_1=.253 degrees.

Interaction effects between Zoom and Attitude - - - - - - - - - - - - - - -

	Z_0	Z_1
A_0	.421 deg.	.355 deg.
A_1	.713 deg	.15 deg.

TABLE 12

Analysis of variance results - Actual values from each repetition.

TABLE 13

Analysis of variance results-Square Root of the Error Mean Square (EMS). A,Z, and T defined in Table .

VARIABLES - F-Statistic/Degrees of Freedom/Significance

	Enroute EMS Variables			Target Recog.		Weapon Release			Weapon Impact		
Source of Variation	Heading Mean	Altitude Mean	Velocity Mean	Time EMS	Slant Range EMS	Time EMS	Altitude EMS	Slant Range EMS	Down Range EMS	Cross Range EMS	Miss Distance EMS
A	.354 1,36 N.S.	.01 1,23 N.S.	.352 1,23 N.S.	.088 1,33 N.S.	.029 1,33 N.S.	.712 1,36 N.S.	.705 1,36 N.S.	.749 1,36 N.S.	.354 1,36 N.S.	.805 1,36 N.S.	.869 1,36 N.S.
Z	.078 1,36 N.S.	.575 1,23 N.S.	1.135 1,23 N.S.	.049 1,33 N.S.	4.3 1,33 .95*	1.08 1,36 N.S.	1.04 1,36 N.S.	.525 1,36 N.S.	1.36 1,36 N.S.	.005 1,36 N.S.	.855 1,36 N.S.
T	.133 2,36 N.S.	.262 2,23 N.S.	.229 2,23 N.S.	.142 2,33 N.S.	.75 2,33 N.S.	.487 2,36 N.S.	.096 2,36 N.S.	.682 2,36 N.S.	.094 2,36 N.S.	.275 2,36 N.S.	.126 2,36 N.S.
AZ	.219 1,36 N.S.	.062 1,23 N.S.	.06 1,23 N.S.	.372 1,33 N.S.	.17 1,33 N.S.	.742 1,36 N.S.	.113 1,36 N.S.	.463 1,36 N.S.	.216 1,36 N.S.	.01 1,36 N.S.	.247 1,36 N.S.
AT	.055 2,36 N.S.	2.28 2,23 .86**	.119 2,23 N.S.	.078 2,33 N.S.	.272 2,33 N.S.	4.164 2,36 .95**	1.221 2,36 N.S.	.169 2,36 N.S.	2.14 3,36 .83**	.414 2,36 N.S.	2.01 2,36 .82**
ZT	1.013 2,36 N.S.	.213 2,23 N.S.	.11- 2,23 N.S.	.533 2,33 N.S.	.431 2,33 N.S.	2.33 2,36 .86***	2.17 2,36 .84***	.425 2,36 N.S.	.363 2,36 N.S.	.42 2,36 N.S.	.59 2,36 N.S.
AZT	.166 2,36 N.S.	1.24 2,23 N.S.	.308 2,23 N.S.	.382 2,33 N.S.	.342 2,33 N.S.	1.31 2,36 N.S.	1.81 2,36 N.S.	.495 2,36 N.S.	.309 2,36 N.S.	1.25 2,36 N.S.	.54 2,36 N.S.

*Mean EMS Slant Range-Z_0= 703.ft.; Z_1= 1634 ft. More variation with zoom.

** See Table for Attitude/Sensor Mounting - Task (AT) interaction.

*** See Table for Zoom-Task (ZT) interaction.

release slant range (i.e., more variation). This does not imply that the subjects did better with zoom or worse without it. It does mean that the subjects were more consistent on target release slant range (consistently good or consistently bad) without zoom than with zoom (Note: No difference observed in miss distance).

Using the actual variables generated only two significant results. These were for zoom on heading mean (see above) and minor significance on weapon release altitude with the slew/weapon task factors. There was a tendency to release the weapon at a higher altitude under Task 3 which was the "smart" bomb with slew. For the EMS variables there were several significant results. Most of the significance was with second degree interaction of task and the other two factors. Table 14 shows this interaction in detail. It may be noted that there exists strong similarity in this interaction across the respective variables. This similarity demonstrates a decrease in consistency (higher EMS's) from Task 1 to Task 3 with the combination attitude display/fixed camera mode but an increase in consistency (decrease in EMS) from Task 1 to Task 3 with the aircraft symbol attitude display/stabilized camera mode. This trend can be seen in three variables with significant, or near significant, interaction.

There were some near significant interactions with the zoom factor and the task factor (See Table 15). There is a similarity across dependent variables here but not as profound or strong as that noted between the display/sensor

TABLE 14

Breakdown of interaction between the attitude display/sensor mode factor and the slew/weapon factor. Tables contain average values of EMS of variables under the different factor conditions.

Altitude Mean EMS

	A_0	A_1
T_0	15.9 ft.	30.3 ft
T_1	25.7 ft.	31.4 ft.
T_2	36.5 ft.	18.3 ft.

Weapon Release Time EMS

	A_0	A_1
T_0	3.13 sec.	3.84 sec.
T_1	2.59 sec.	3.12 sec.
T_2	4.43 sec.	1.86 sec.

Down Range EMS

	A_0	A_1
T_0	570 ft.	1224 ft.
T_1	490 ft.	1110 ft.
T_2	1095 ft.	373 ft.

Miss Distance EMS

	A_0	A_1
T_0	374 ft.	1200 ft.
T_1	387 ft.	967 ft.
T_2	884 ft.	321 ft.

TABLE 15

Breakdown of interaction between zoom factor and task factor. Tables contain average EMS values of the variables under different factor conditions.

Weapon Release Time EMS

	Z_0	Z_1
T_0	3.92 sec.	3.06 sec.
T_1	2.56 sec.	3.15 sec.
T_2	2.20 sec.	4.10 sec.

Weapon Release Altitude EMS

	Z_0	Z_1
T_0	267 ft.	212 ft.
T_1	234 ft.	262 ft.
T_2	186 ft.	335 ft.

mounting mode factor and the task factor. Here the availability of zoom tended to make for more consistency on Tasks 1 and 2 and less consistency on Task 3. Without zoom this relationship tended to reverse with more consistent performance on Tasks 2 and 3 and less consistency on Task 1.

Table 16 shows the various performance measures for the individual subjects. This table includes the mean, standard deviation and number of valid observations for the variables for all runs per subject and for all subjects. Correlations were calculated between all these variables and the run number and repetition number to try to detect any overall learning (i.e., improvement of scores with experience) in the simulation. These correlations are shown in Table 17 .

The only significant (.95 level of significance) correlation was between run number and weapon release time. The positive correlation here indicates that the subjects tended to release the weapon [illegible] in the mission as the experiment progressed.

Subject		Heading Mean in Degrees	Altitude Mean in Feet	Velocity Mean GPS	Camera Mvmt. Pitch	Camera Mvmt. Yaw	Pitch & Yaw Correlation	Target Recog. Time.	Target Recog. Slant Range	Weapon Release Time	Weapon Rel. Altitude	Weapon Rel. Slant Range	Miss Distance
13	Mean	-.1683	439	458	.45	2.14	-.194	53.	8784	72	560	1992	513
	S.D.	1.68	25.2	17.3	.49	1.32	.376	7.03	1970.	5.75	342	808	358
	Obs.	24	24	24	15	15	15	22	22	22	22	22	22
14	Mean	.143	No Valid Observations		2.34	4.03	-.08	51.	8328	64.5	570	2837	624
	S.D.	.85			1.29	1.86	.35	5.63	2190	5.	238	1170.	434
	Obs.	24			15	16	16	19	19	23	23	23	22
15	Mean	.63	No Valid Observations		.844	1.3	-.259	47.	7706	68.	681	3323	770
	S.D.	.92			.908	1.07	.473	3.38	65.	4.15	395	1680	496
	Obs.	24			15	15	15	22	22	19	19	19	19
16	Mean	.435	430	491	3.03	2.36	.20	53	6415	62	745	21450	473
	S.D.	1.08	24.1	1.64	1.43	1.56	.424	5.73	2290	4.21	360	3250	342
	Obs.	24	20	20	16	16	16	23	23	24	24	24	24
17	Mean	.474	445	500	.937	.386	-.04	49	7721	61	759	2689	1680
	S.D.	.806	44.3	31.8	1.1	.723	.512	6.27	2310	7.1	353	1600	2735
	Obs.	24	24	24	16	16	16	22	22	20	20	20	20
18	Mean	.377	431	517	2.46	.322	.466	46	8113	58	652	2966	1002
	S.D.	.58	37.4	7.28	1.5	.366	.538	2.89	1360	4.04	155	1665	1050
	Obs.	24	24	24	16	16	16	24	24	24	24	24	24
19	Mean	.79	432	499	1.21	1.59	.034	45	9171	57	1200	4587	1753
	S.D.	.746	34.2	8.25	1.73	1.6	.554	4.3	1690	4.83	399	1605	2465
	Obs.	24	24	24	16	16	16	23	23	21	21	21	21
20	Mean	.60	425	481	3.59	1.09	-.006	55	7050	60	780	3761	1775
	S.D.	1.14	34.6	25.4	1.7	1.88	.575	3.12	1170	5.5	360	1520	3200
	Obs.	24	24	24	16	16	16	10	10	24	24	24	24
All Subj	Mean	.396	434	491	1.99	1.69	.018	49.5	7969	61.3	740	5645	1066
	S.D.	1.18	34.3	26.2	1.67	.55	1.71	5.95	2000	6.94	381	3160	2085
	Obs.	192	140	140	126	126	126	165	164	177	177	177	177

TABLE 16

Performance measures for individual subjects and all subjects for various variables.

TABLE 17

Correlations between runs and repetitions and all other variables. Indication of overall learning.

	Heading	Altitude	Velocity	Camera Pitch Movement	Camera Yaw Movement	Correlation	Target Recog. Time	Target Recog. Slant Range	Weapon Release Time	Weapon Release Altitude	Weapon Release Slant Range	Miss Distance
Correlation												
Runs	-.204	.11	-.17	.0025	.062	.14	.185	-.018	.3144*	-.138	-.115	-.155
# of Valid Observations	190	140	140	126	126	126	165	164	177	177	177	177
Correlation	.00753	.046	-.019	.031	-.1475	.035	-.047	.035	.067	-.042	-.039	-.029
Repetitions	190	140	140	126	126	126	165	164	177	177	177	177
# of Valid Observations												

*Significant at .95 level of significance

APPENDIX L

ANALYSIS OF WITKIN EMBEDDED FIGURES TEST SCORES FOR EXERPIMENT II

The object of this analysis is to determine if a positive relationship exists between error scores and Embedded Figures Test scores under the conditions of contradictory display formats. This analysis was accomplished as an additional exploratory study since data was available. The formats that were considered were as follows:

Phase 1 -

1. Aircraft symbol (behaves like artificial horizon, inside-out) and stabilized TV camera
2. ADI (inside-out) and stabilized TV camera
3. ADI, aircraft symbol, and stabilized TV

Phase 2 -

1. Aircraft symbol (outside-in) and fixed TV camera (inside-out)
2. ADI and stabilized TV

Phase 3 -

1. Aircraft symbol (outside-in) and fixed TV
2. Artificial horizon (inside-out) and stabilized TV.

Considering that different phases of the experiment were not performed under homogenous conditions, direct error scores could not be used for the correlation analysis. To avoid this problem and still utilize all subjects in the analysis, individual scores were normalized within each phase.

Normalized scores were then ranked over all subjects with the EFT Scores (See Table 7). The Spearman Rank Correlation Coefficient was then calculated between EFT ranks and each variable and also between EFT and the average rank over all variables.

As can be seen on Table 7, no significance was reached although, as hypothesized, there was a definite tendency towards positive correlation since all variables had positive correlations with the EFT Scores. This indicated that possibly under more stringent test conditions with a larger number of subjects and with a parametric multivariate test statistic (such as the multiple correlation coefficient) a significant positive relationship would appear. Additionally, it must be noted that as a group pilots exhibit definite Field Independent behaviors (Cullen, 1969). Since only pilots were used as subjects in this study, EFT scores elicited were all below published norms. Differentiation was thus accomplished with persons who all exhibit Field-Independent abilities; therefore, to obtain significant differences in behavior along the Witkin continuum would be a more stringent task.

TABLE 18

CORRELATION ANALYSIS FOR EFT SCORES

TABLE 18A

Ranking of Subjects with Respect to the Normalized Error Scores and EFT

VARIABLES

Subject No.	Phase	Pitch Reversals	Roll Reversals	Resp. Time	Correct Move	Compl. Time	Acft. Move	Av. Rank	EFT
1	I	9	2	9	8	3	8	6.5	3.5
2	I	2	8	1	3	8	3	4.17	1
3	II	5	7	6	10	6	10	7.3	5
4	II	8	6	5	6	2	2	4.83	9
5	II	3.5	4.5	4	1	10	6	4.83	8
6	II	3.5	4.5	8	5	4	4	4.83	2
7	III	6.5	1	3	4	5	5	4.083	6
8	III	6.5	9.5	7	7	7	9	7.67	10
9	III	1	3	2	2	1	1	1.67	3.5
10	III	10	9.5	10	9	9	7	9.1	7

TABLE 18B

Spearman Rank Correlations with EFT Scores

Variable	r_s	Significance*
Pitch Reversals	.5	N.S.
Roll Reversals	.306	N.S.
Response Time	.221	N.S.
Time to Correct Movement	.179	N.S.
Completion Time	.227	N.S.
Aircraft Movement	.306	N.S.
Average Rank	.536	N.S.

*An r_s of .56 is significant at the .95 level.

GLOSSARY

F_z	Downward Force (lb)
ρ	Atmospheric Density (slug/ft^3)
M	Vehicle Mass (slug)
C_{zo}	Normal Force Coefficient at Zero Angle of Attack
U	Forward Body Component of Velocity (ft/sec)
V	Sideward Body Component of Velocity (ft/sec)
W	Downward Body Component of Velocity (ft/sec)
S	Reference Area (ft^2)
$C_{z\alpha}$	Normal Force Coefficient Slope with Angle of Attack (1/rad)
F_x	Forward Force (lb)
F_y	Sideward Force (lb)
Tmax	Net Maximum Thrust (lb)
δ_t	Per Cent of Maximum Thrust
C_{xo}	Body Drag Force Coefficient at Zero Angle of Attack
$C_{x\alpha}$	Body Drag Force Coefficient with Respect to Angle of Attack (1/rad)
$C_{x\alpha^2}$	Body Drag Force Coefficient with Respect to Angle of Attack Squared (1/rad^2)
$C_{y\beta}$	Side Force Coefficient due to Sideslip Angle (1/rad)
M_x	Roll Moment (ft-lb)
M_y	Pitch Moment (ft-lb)
M_z	Yaw Moment (ft-lb)
c	Mean Aerodynamic Chord (ft)

b	Wing Span (ft)
I_x	Roll Moment of Inertia (slug-ft^2)
I_y	Pitch Moment of Inertia (slug-ft^2)
I_z	Yaw Moment of Inertia (slug-ft^2)
$C_{m\alpha}$	Pitch Moment Coefficient with Respect to Angle of Attack (1/rad)
$C_{m\delta e}$	Pitch Moment Coefficient with Respect to Elevator Deflection (1/deg)
C_{mq}	Pitch Moment Coefficient with Respect to Pitch Rate (1/rad/sec)
$C_{l\beta}$	Roll Moment Coefficient with Respect to Sideslip Angle (1/rad)
C_{lp}	Roll Moment Coefficient with Respect to Roll Rate (1/rad/sec)
$C_{l\delta a}$	Aileron Effectiveness (1/deg)
$C_{n\beta}$	Yaw Moment Coefficient with Respect to Sideslip Angle (1/deg)
C_{nR}	Yaw Moment Coefficient with Respect to Yaw Rate (1/rad/sec)
$C_{n\delta r}$	Rudder Effectiveness (1/deg)
g	Gravity (32.17 ft/sec^2)
P	Roll Rate (rad/sec)
Q	Pitch Rate (rad/sec)
R	Yaw Rate (rad/sec)
ψ	Yaw Angle (rad)
θ	Pitch Angle (rad)

ϕ	Roll Angle (rad)
$\dot{X}$	Northern Velocity Component (ft/sec)
$\dot{Y}$	Eastward Velocity Component (ft/sec)
$\dot{H}$	Rate of Climb (ft/sec)
δ_e	Elevator Deflection (deg)
δ_a	Aileron Deflection (deg)
δ_r	Rudder Deflection (deg)
δ_{PITCH}	Fore and Aft Center Stick Deflection (%)
δ_{ROLL}	Sideward Motion of the Center Stick (%)
δ_{YAW}	Rudder Pedal Deflection (%)
s	LaPlace Transform Operator (1/sec)
$\Psi_{COMMAND}$	Pilot Yaw Camera Command (deg)
$\theta_{COMMAND}$	Pilot Pitch Camera Command (deg)
Ψ_{CAMERA}	Camera Yaw Angle with Respect to the Vehicle (deg)
θ_{CAMERA}	Camera Pitch Angle with Respect to the Vehicle (deg)
ϕ_{CAMERA}	Camera Roll Angle with Respect to the Vehicle (deg)
τ_s	Smoothing Time Constant (sec)
H_v	Apparent Camera Altitude (ft)
Z	Zoom Ratio
X_v	Apparent Camera X Position (ft)
Y_v	Apparent Camera Y Position (ft)
X	Vehicle Northward Position (ft)
Y	Vehicle Eastward Position (ft)
H	Vehicle Altitude (ft)